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Roadway Striping Productivity Data Analysis for INDOT Greenfield and Crawfordsville Districts

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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

The main objective of the SPR-3650 project is to provide an accurate overview of striping operation so that INDOT finds a way to effectively save significant investment for purchasing new striping trucks in near future without compromising roadway striping operation and maintenance. Telematics technology was used to collect 2012 striping season operation data collection, from April 2012 to November 2012, in real-time via wireless network to analyze striping operation performance mainly focusing on four striping trucks in the Crawfordsville and Greenfield district. The study focused productivity and utilization as key performance components. Productivity and utilization analyses revealed that there is significant opportunity to improve. As a result of data analysis, four recommendations and performance metrics were suggested. Several statistical techniques such as Monte Carlo simulation and triangular distribution model were used to develop the performance metrics. An expected further outcome of the study is that new data collection system provides an opportunity to improve various INDOT roadway maintenance operations.

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EXECUTIVE SUMMARY

ROADWAY STRIPING PRODUCTIVITY DATA ANALYSIS FOR INDOT GREENFIELD AND CRAWFORDSVILLE DISTRICTS

Introduction

Roadway striping is a crucial component in maintaining public safety and managing traffic flow. It serves as an important informational tool for conveying official information to motorists, pedestrians, and cyclists. Roadway striping deteriorates over time due to heavy traffic, weathering, and other paint degradation factors. It therefore requires regular maintenance and re-striping. The Indiana Department of Transportation (INDOT) is responsible for roadway striping throughout the entire state of Indiana, and the current annual cost of the INDOT roadway striping program is approximately $4.4 million. INDOT is seeking to improve roadway striping performance while minimizing overall costs. For this study, performance is defined as a combination of productivity and utilization improvement. Productivity indicates striping distance in an operation day and utilization refers to the number of operation days in a month. INDOT currently operates twelve striping trucks in six districts. Each district independently utilizes two striping trucks: one centerline truck and one edgeline truck. Each district is also responsible for executing its own striping scheduling and plans to meet the annual amount of striping work.

Telematics is defined as the integrated use of wireless telecommunication and operation data collection systems. In this study data was collected from telematics sensors and remotely transmitted via wireless technology to a database system on the web.

The main objective of this study was to provide an accurate overview of striping operations in the Crawfordsville and Greenfield districts to be used as a baseline for decision making aimed at improving striping efficiency. Telematics has proven to be an effective technology for providing real-time tracking and operational data to analyze current performance and a baseline for developing metrics to measure future performance.

Findings

Partial operational data from the 2011 striping operation was used to verify the system hardware configuration and setup. This process was required due to the complexity of the striping operation pattern and telematics device sensors. This study mainly used operation data collected from a single striping season between April 1, 2012, and November 30, 2012. Centerline and edgeline trucks have different patterns of operation. The centerline truck sprayed either single or multiple stripes using solid or skipped lines, while the edgeline truck sprayed a single stripe in a less complicated process.

The production algorithm was determined to measure only driving distance while striping. The average productivity (production rate) of a centerline truck was 18.3 miles/day in Crawfordsville and 17.1 miles/day in Greenfield. Crawfordsville and Greenfield districts operated on 66 and 80 days out of 244 calendar days, respectively, during the striping season. The centerline production rate ratio between total driving distance and striping distance is only approximately 15 percent. Productivity rates for the edgeline trucks are 29.5 miles/day in Crawfordsville and 30.6 miles/day in Greenfield. The edgeline trucks were operated only 46 days in Crawfordsville and 44 days in Greenfield. The edgeline production rate ratio between total driving distance and striping distance is only approximately 25 percent. The productivity analysis revealed that there was a significant opportunity to improve low productivity in terms of actual striping distance as compared to total driving distance.

Utilization is defined as the ratio between a number of operation days and calendar days, or weekdays, in a month. An operation day is counted whenever a truck stripes, regardless of the production rate. The Greenfield district operated with the highest centerline truck utilization rate at approximately 46 percent, and lowest edgeline truck rate at 25 percent over all weekdays. The Crawfordsville district operated with a centerline rate at 38 percent and edgeline rate at 26 percent over all weekdays.

Idling analysis provides a measurement of vehicle operation inefficiency in terms of excessive unnecessary fuel consumption and idling between striping operations. Idling is defined as cumulative time while the engine is running but a truck is not moving. A total of 268 idling hours were recorded by the telematics, and an estimated 268 gallons of diesel fuel, using a 1 gal/hour rate, could have been saved. Additional maintenance cost due to idling was estimated to be $892. Savings from this idling analysis seems insignificant. However, cumulative savings throughout the entire state, considering all supporting vehicles and trucks in all districts, would become significant.

Operational data obtained from the INDOT Work Management System (WMS) was compared to the telematics data. The study showed that potential human error occurred during the WMS manual input process. Materials analysis was conducted to provide a material consumption baseline. Centerline trucks primarily used yellow paint and some white paint. Edgeline trucks only used white paint. The analysis revealed that the Greenfield centerline truck applied more white striping paint than the Crawfordsville truck. Average paint and bead consumption for the striping trucks was approximately 17 gal/mile and 100 lbs/mile, respectively. Real-time GPS operation tracking is an advantage of using telematics. The geospatial operation tracking function has been successfully updated to present striping operation patterns on the webpage.

The existing operational boundary was examined to find any potential alternative operational boundaries for striping trucks. The results revealed that sub-district area striping operations from the center of a district location had the highest productivity as compared to other sub-districts in a district. Operational boundaries could possibly be reorganized to improve production rates by utilizing a smaller operational boundary in which a truck completes striping workloads within one sub-district before moving to the next sub-district.

Based on productivity and utilization analysis during the 2012 striping season, the study developed four alternative recommendations that improve overall productivity (striping mileage per operation day) and utilization (number of operation days in a month). The recommendations focused on (1) reducing the number of existing striping trucks, (2) modifying work schedules, and (3) possibly integrating administrative district boundaries. The maximum cost savings and striping production rate could be obtained from scenario 2 using a centerline truck and an edgeline truck in two districts. Scenario 4 might be the most plausible scenario smoothly transitioning from the current operation plan because it maintains district independency and provides an edgeline truck as a backup.

Performance metrics were developed as a baseline of future performance measurement. Performance metrics include productivity and utilization for the four striping trucks. Monte Carlo simulation was selected to develop productivity metrics. The main objective of Monte Carlo simulation was to simulate striping productivity based on 2012 striping operation data. The expected outcome of this method was to provide simulated population data for developing productivity metrics. The productivity metrics were divided into three categories: (1) low productivity—when the calculated value is less than or equal to 30 percent of the mean value derived from Monte Carlo simulation; (2) medium productivity—when the value is more than 30 percent and less than or equal to 70 percent; and (3) high productivity—when the value is over 70 percent.

The 2012 striping utilization data, summarized by using the number of operation days in each month, are insufficient for a normal distribution. Therefore, the triangular distribution statistical model can be a suitable method for utilization metrics. A primary goal of utilization metrics is to determine levels of utilization without comprehensive analysis of striping operation data. Utilization also represents the effectiveness of striping operation scheduling and planning between districts. To be consistent, the same three categories are used for utilization metrics: (1) low utilization (less than or equal to 30 percent); (2) medium utilization (more than 30 percent and less than or equal to 70 percent); and (3) high utilization (over 70 percent).

Implementation

The striping operation data was obtained from actual observed operation for the four striping trucks in the two districts. Productivity and utilization analysis revealed that much higher daily production and monthly utilization were possible. The impact of the study is summarized in threefold: (1) the telematics data collection was proved to be effective in observing actual striping operations; (2) the data analysis shows there is significant opportunity for performance improvement; and (3) the study provides a baseline of the striping operation and performance metrics to measure future striping productivity and utilization. Currently, INDOT has already implemented one of the four scenarios, and considered a hybrid type of alternative operation plan, in the two districts. INDOT management expects to significantly reduce capital investment by maximizing the performance of existing striping trucks and optimizing the fleet size. Future study may be necessary to continue the efforts of improving performance in other INDOT roadway maintenance operations and to evaluate new striping operation plan implementations.

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1. INTRODUCTION

The term "telematics" is defined as the integrated use of wireless telecommunication and informatics. Telematics is used to collect data from hardware devices and transmit data from remotely deployed equipment to a database system utilizing wireless technology without compromising equipment operation and productivity. Telematics technologies, utilizing real-time tracking, can provide an advanced mechanism for tracking equipment operation, generating analytical data, and providing recommendations that can improve overall equipment operation effectiveness. The value and potential of telematics is recognized in other areas and applications, but the return on investment (ROI) has often been difficult to ascertain mainly because of the lack of appropriate data from existing practices, such as the Indiana Department of Transportation's (INDOT's) roadway maintenance operations, over extended periods of time. To verify potential uses of telematics for INDOT maintenance operations, INDOT established a research and pilot case study to verify the usefulness of telematics technology.

Roadway striping is a crucial component in maintaining public safety and managing traffic flow. It serves as an important informational tool in conveying official information to motorists, pedestrians, and cyclists. Roadway striping deteriorates over time due to heavy traffic, weathering, and other paint degradation factors. It therefore requires regular assessment and maintenance. INDOT is responsible for maintaining highway surface markings over six districts, including the Greenfield and Crawfordsville districts. The annual cost of the INDOT roadway striping program is approximately \$4.4 million. In the spirit of continuous improvement, INDOT is seeking to improve roadway striping performance while minimizing overall costs.

INDOT currently operates twelve striping trucks in six districts throughout the state of Indiana. Each district independently utilizes two striping trucks, one centerline and one edgeline, and follows its own internal process to execute annual work plans. These processes vary statewide and the best practice is difficult to determine. A roadway striping operation requires significant amounts of resources and coordination including a skilled crew, striping materials, striping trucks, and support vehicles. Examining and comparing current roadway striping practices and strategies among districts would enable the development of shared systems and strategies that could be implemented across the state, fostering economies of scale and higher efficiency. The main objective of this research is to provide an accurate overview of striping operations that provides a baseline for decision making aimed at improving striping efficiency. Several new roadway striping plan alternatives and performance metrics were developed in this final report and recommended to INDOT.

2. LITERATURE AND TECHNOLOGY REVIEW

Transportation agencies are responsible for ensuring effective and efficient roadway maintenance operations. This responsibility requires the dedication of millions of dollars into operation and maintenance (O&M) budgets to ensure that the public roadway system supports the economy and society at large. For example, INDOT spends over four (4) million dollars annually just on roadway striping operations. Currently, INDOT's roadway striping operation management is conducted by using manual planning and data collection processes.

Information technology (IT) has dramatically improved data processing and monitoring capability in many project management areas. For example, IT applied automation technology, in combination with global positioning system (GPS) coordinates data, can enhance construction equipment productivity and minimize subjective human intervention in earthwork equipment applications (*1*). The repetitive and tedious nature of construction processes, such as on-site heavy equipment operations on earthmoving jobsites, makes IT applications particularly desirable (*2*). In addition to IT applied automation technology, significant advancement of IT implementation in areas such as finance and cost controls, estimating and scheduling software, and simulations has evolved. However, the majority of field performance data is still reported and collected manually (*3*). Manual data collection and input processes limit access to accurate and real-time performance data (*4–7*). Manual data collection results in ineffectiveness (*8*) and creates a need for a process that can possibly eliminate human reporting errors and increase the productivity rate of field operations. This process is called automated data collection (ADC). Previous studies revealed that ADC could reduce cost and ensure timely and valid data on field operations (*9–12*). Another new area of technological development is automated vehicle tracking data collection, such as automatic vehicle location (AVL). AVL combines data from a geographical information system (GIS), global positioning system (GPS), and wireless data collection systems. The AVL system can help transportation agencies manage and monitor their fleet of vehicles effectively and increase the available information about vehicle activities to improve fleet productivity (*13,14*).

The first AVL system used in the transit industry was in London in the late 1950s and was implemented in the United States in the late 1960s (*15*). There has been a substantial increase in the number of transit agencies that use AVL systems since 1995 (*16*). The use of AVL technology is not limited to the transit industry. The system utilization in different industries such as paratransit services, logistics, public transport operations, police cars and ambulances has increased since the mid-90s (*17,18*). In addition, according to the Intelligent Transportation Systems (ITS) deployment survey (*19*), AVL technology had begun to be used for winter maintenance operations. A typical AVL system is mainly based on automated geographic locating and information transmission. The entire system is composed of three core parts: (1) GPS satellite, (2) receiver on the vehicle and (3) radio system with PC based tracking software for dispatch (*20*). As presented in Casey's 1998 report (*21*), AVL systems use one or more of the following location technologies: (1) dead-reckoning, (2) signpost and odometer, (3) global positioning system (GPS), and/or (4) differential GPS. Each technology has its benefits and shortcomings. Table 2.1 summarizes the advantages and disadvantages of each location technology (*22*). With the advent of free GPS signals and the development of modern satellites, the use of GPS-based location technology has increased.

An AVL system can be used when tracking one vehicle or a fleet of vehicles (*23*). It also provides real-time information about the position, location and activity of vehicles and can store that information in data management servers over a long time period for future analysis (*14*). Other than real-time information analysis, the archived data analysis is becoming more important for fleet performance management. Off-line historical data analysis is used by transit agencies to optimize vehicle operation and scheduling (*24*).

AVL technology is one of the applications of Intelligent Transportation Systems (ITS). According to the ITS deployment survey (*25*) there were 10 states deploying ITS technologies to manage maintenance vehicles. AVL technology is becoming more popular with transportation agencies. The cost of organizing and sustaining an AVL system has been expensive, however it is getting more affordable and becoming more popular during recent years (*23*). Numerous studies have recognized the benefits of AVL systems. According to Morlok (*26*), Lee et al. (*13*) & Aloquili et al. (*23*), AVL technology benefits public transportation agencies by reducing overall operation and maintenance costs, increasing efficiency of bus schedules and improving overall bus service quality. Although numerous studies have been conducted specifically on AVL applications in public transportation agencies, there is no prior work that studies the implementation of AVL applications for analyzing performance in roadway striping operations.

Telematics technology is an advanced approach using benefits of all previous technologies from IT, AVL, and ADC. Telematics technology enables operation managers to collect various field data in conjunction with real-time GPS location data directly and operational data from numerous pre-configured sensors through a wireless network to an IT based web server. Telematics technology is capable of providing an advanced roadway maintenance management mechanism by documenting existing activities, storing data in a database system, and generating analytical data in predetermined formats. Two key objectives of implementing telematics technologies are (1) increasing data collection efficiency and effectiveness, and (2) reducing overall maintenance operation costs.

Gauge Telematics (GT) is the main technology provider for this project. Telematics technology has been configured to INDOT's striping operation process. Striping operations involve mobile crews performing roadside maintenance at different locations every day. To address this challenge the utilization of telemetry is required to establish a baseline of operations which are not skewed by the presence of additional management or observers on work sites. This is critical in establishing data that is an accurate depiction of daily activities. Within each district, striping trucks and support vehicles will be equipped with hardware that collects geo-spatial data

TABLE 2.1
The Advantages and Disadvantages of Locating Technologies (*22*)

Type	Advantages	Disadvantages
Dead reckoning	Relatively inexpensive Self-contained on vehicle (no infrastructure costs) Only odometer needed (if on route is assumed)	Accuracy degrades with distance traveled (errors can accumulate between known locations) Requires direction indicator and maybe map matching for off-route use Corrupted by uneven road surfaces, steep hills, or magnetic interference
Signpost and odometer	Low in-vehicle cost No blind spots or interference Repeatable accuracy	Requires well-equipped infrastructure No data outside of deployed infrastructure Frequency of updates depends on density of signpost
GPS (Global Positioning System)	Moderately accurate Global coverage Moderate cost per vehicle	Signal attenuation by foliage and tunnels Subject to multi-path errors
DGPS (Differential Global Positioining System)	Very accurate Moderate cost per vehicle	Signal attenuation by foliage and tunnels Subject to multi-path errors Must be within range of differential signal Differential correction must be updated frequently

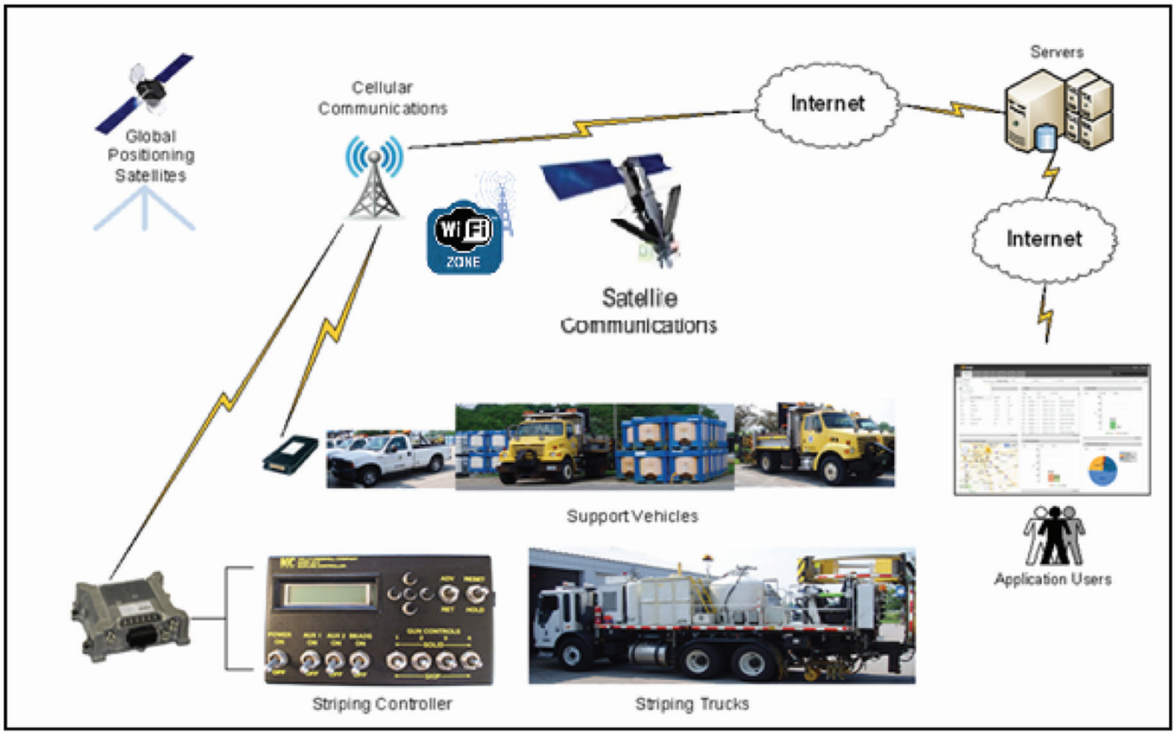

Figure 2.1 Telematics data collection network.

and other key data points relevant to the production of the striping crews. As illustrated in Figure 2.1, the data will be transmitted over the GSM cellular network to the Gauge Telematics data servers on a periodic basis. Because striping operations can occur in locations out of the GSM cellular network or can temporarily shut down due to various reasons, data can be temporarily stored and re-sent when the GSM cellular network is resumed. The data will be processed and stored in an enterprise level database and accessed through a web application for analysis and report generation.

Although each district operates its own style of operational management for roadway striping, the typical striping operation process is similar in Crawfordsville and Greenfield districts, as shown in Figure 2.2. Actual striping productivity utilization focuses on striping distance per day. Most striping operations are scheduled daily. Currently the Work Management System (WMS) is the only management tool officially adopted by INDOT and is primarily used to record usage of various resources. WMS has some limitations: (1) it is not designed to provide real-time striping process monitoring and location tracking; (2) WMS makes it difficult to measure striping operations productivity; and (3) WMS is a manual data input system, therefore, not immune to human data input error and other disruptions that may occur during the data input process.

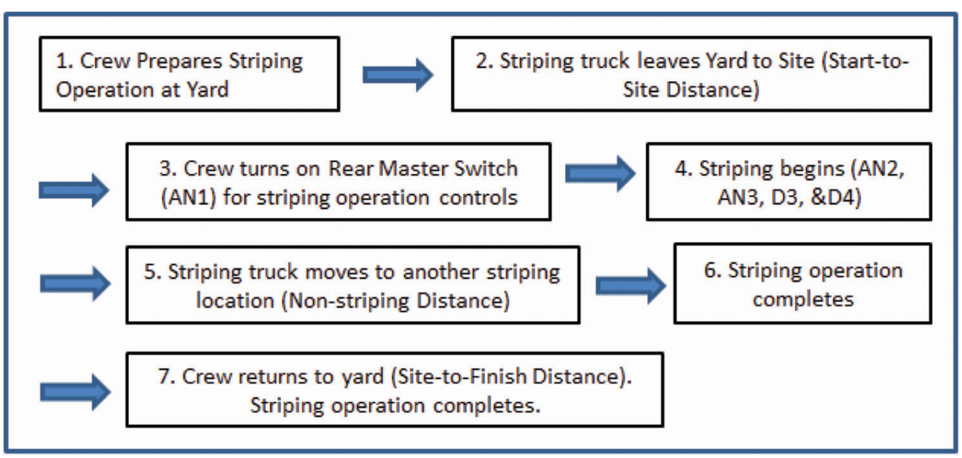

Figure 2.2 Striping operation process map.

This study exclusively used telematics data collection provided by Gauge Telematics (GT). The data was collected partially during 2011 striping operation to configure and confirm functionality of initial installations and during entire 2012 striping operation for actual performance analysis from the Crawfordsville and Greenfield districts. All collected data can be retrieved from GT's website including all location, productivity and utilization data.

3. TELEMATICS INSTALLATION

Telematics devices were installed and updated as presented in Tables 3.1 and 3.2. Telematics devices have required continuous updates due to equipment configuration changes and data collection updates for new equipment setup. However, the number of updates is expected to be significantly reduced once telematics configuration is completed. Tables 3.1 and 3.2 show a list of telematics device installation and update sequences for the striping trucks and supporting vehicles from the Crawfordsville and Greenfield districts.

Figures 3.1 and 3.2 show photos of the telematics device field installation for striping trucks and support vehicles. Figure 3.2 also shows the complexity of wiring and connections from electronic sensors in the control box to the telematics device. Changes to the sensor connection without proper configuration may disrupt data collection.

Tables 3.3 and 3.4 present types of data configured in the telematics devices installed in two centerliner trucks, two edgeliner trucks, and eight supporting vehicles. A centerliner can be alternately used for both edgeline and centerline painting, but an edgeliner can only paint a right side edgeline in a forward direction. Geospatial coordinates (GPS) track automatically every data point to indicate exact locations of the striping trucks on a map. Data is configured to synchronize with geospatial coordinates along time, travel distance, striping and speed data. For the support vehicles, the telematics device was only connected to the primary engine sensor due to the simplicity of vehicle operation.

Tables 3.5 and 3.6 present a data collection summary of striping trucks and supporting vehicles in Crawfordsville and Greenfield districts. Data is not available for Asset No. 61460-Crawfordsville stake bed pickup and Asset No. 63855-Greenfield stake bed truck on the telematics webserver. Data collection for support

TABLE 3.1
Crawfordsville Telematics Device Installation Information

Asset Code	Category	Model & Year	Device Installation	First Update	Second Update	Third Update
61457	Striping Truck—Centerliner	2006 Sterling Condor	9/19/11 12:00:00 AM	3/22/12 7:31:50 PM	—	—
61249	Striping Truck—Edgeliner	2004 Autocar WX	9/19/11 12:00:00 AM	3/22/12 6:30:25 PM	3/22/12 7:29:39 PM	—
61133	Single Axle Dump Truck	2003 Sterling L7500	9/8/11 8:00:00 AM	9/12/11 4:59:33 PM	3/22/12 7:22:03 PM	—
61288	Single Axle Dump Truck	2005 Sterling L7500	9/19/11 12:00:00 AM	3/22/12 7:20:49 PM	—	—
61118	2 Ton Stake Bed Truck	2003 International 4200	9/8/11 9:00:00 AM	9/12/11 5:06:15 PM	3/22/12 7:09:16 PM	3/22/12 7:18:05 PM
61460	Crew Cab Stake Bed Pickup	2006 Ford F650	9/8/11 9:00:00 AM	9/12/11 5:01:18 PM	03/22/2012 19:26	—
61459	Full Size Pickup	2007 Ford F250	9/12/11 4:57:23 PM	09/19/2011 0:00	9/21/11 12:29:40 AM	3/22/12 7:24:14 PM

TABLE 3.2
Greenfield Telematics Device Installation Information

Asset Code	Category	Model & Year	Device Installation	First Update	Second Update	Third Update
63597	Striping Truck—Centerliner	2005 STERLING Condor	9/9/11 11:00:00 AM	9/12/11 5:18:17 PM	3/26/12 7:36:45 PM	—
63759	Striping Truck—Edgeliner	1995 White GMC WX Xpeditor	9/2/11 2:51:00 PM	9/5/11 4:16:50 PM	2/17/12 3:30:56 PM	3/26/12 7:33:41 PM
63854	2 Ton Stake Bed Truck	2009 FORD F350 PICKUP	9/9/11 8:00:00 AM	9/12/11 5:08:21 PM	—	—
63855	2 Ton Stake Bed Truck	2009 FORD F350 PICKUP	—	—	—	—
63713	Crew Cab Stake Bed Pickup	2006 FORD F350 PICKUP	9/9/11 12:00:00 AM	9/12/11 5:10:15 PM	—	—
63749	Crew Cab Stake Bed Pickup	2007 FORD F350 PICKUP	9/9/11 12:00:00 AM	9/12/11 5:12:19 PM	3/26/12 7:30:20 PM	—

Figure 3.1 An edgeline truck—Autocar WX striping truck (61249).

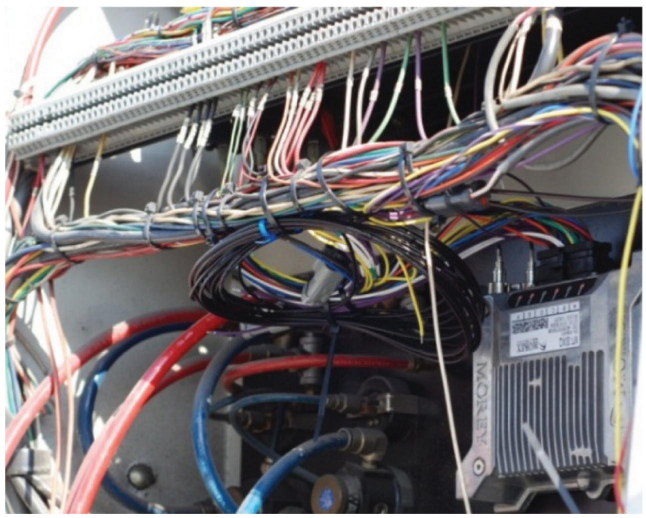

Figure 3.2 Telematics device installation on a striping truck.

TABLE 3.3
Hardware Configuration Sensor Codes for Striping Trucks

District	Crawfordsville		Greenfield	
Data	Centerliner	Edgeliner	Centerliner	Edgeliner
Code Name	61457	61249	63597	63759
Primary Engine (Engine 1)	D1	D1	D1	D1
Compressor Engine (Engine 2)	D2	D2	D2	D2
Master Switch For Rear Striping Controls	AN1	AN1	AN1	AN1
Left Solid	AN2	N/A	AN2	N/A
Right Solid	AN3	AN3	AN3	AN3
Left Skip	D3	N/A	D3	N/A
Right Skip	D4	D4	D4	D4

NOTE: N/A means that no connection is established between the telematics device and a signal code.

TABLE 3.4
Hardware Configuration Sensor Codes Supporting Vehicles

District	Crawfordsville		Greenfield	
Data	Dump & Bed Trucks	Pickup Trucks	Dump & Bed Trucks	Pickup Trucks
Code Name	61133 61288 61118	61460 61459	63854	63713 63749
Primary Engine (Key On and Off)	Connected	Connected	Connected	Connected

TABLE 3.5
List of Crawfordsville Assets

Asset Code	Asset Category	Model & Year	Data
61457	Striping Truck—Centerliner	2006 Sterling Condor	Completed
61249	Striping Truck—Edgeliner	2004 Autocar WX	Completed
61133	Single Axle Dump Truck	2003 Sterling L7500	Partially Completed (from April 1, 2012 to August 7, 2012)
61288	Single Axle Dump Truck	2005 Sterling L7500	Completed
61118	2 Ton Stake Bed Truck	2003 International 4200	Completed
61460	Crew Cab Stake Bed Pickup	2006 Ford F650	Not collected
61459	Full Size Pickup	2007 Ford F250	Completed

TABLE 3.6
List of Greenfield Assets

Asset Code	Category	Model & Year	Data
63597	Striping Truck—Centerliner	2005 STERLING Condor	Completed
63759	Striping Truck—Edgeliner	1995 White GMC WX Xpeditor	Completed
63854	2 Ton Stake Bed Truck	2009 Ford F350 Pickup	Completed
63855	2 Ton Stake Bed Truck	2009 Ford F350 Pickup	Not collected
63713	Crew Cab Stake Bed Pickup	2006 Ford F350 Pickup	Completed
63749	Crew Cab Stake Bed Pickup	2007 Ford F350 Pickup	Completed

vehicles including asset code 61133, 61460, 63855 was not completed due to unexpected incidents such as wreck damage needing repair.

4. 2011 PILOT DATA ANALYSIS

Some data had been collected from roadway striping field operations in the Crawfordville and Greenfield districts. The data was considered as pilot data prior to the entire 2012 striping season operation and the initial productivity data analysis was tested. Telematics devices collected and transmitted hundreds of data points per day from each striping truck. The data signals including AN1, AN2, AN3, D1 and D2 have signal thresholds to be recorded as designated operational signals. Those signals are recorded as “ON” when it is above the threshold and “OFF” when it is below the threshold. Two digital signals, including D3 and D4 for skip line signals, do not have “OFF” and only recorded “ON” because of the frequent pulse sequence of striping data for skipped lines. Therefore, recording D3 and D4 data can be extremely overwhelming, and was not set up during sensor configuration.

The data collected during Fall 2011 was limited to only 32 total days from all four striping truck operations during a nine week period. It averaged only eight operation days per each striping truck. Tables 4.1 and 4.2 show a summary of mileage retrieved from telematics data. A striping operation typically runs on a daily basis. A few typical operation examples are shown in Figures 4.1 and 4.2. Only the master switch for the rear striping control signal (AN1) was used to determine striping activity and non-striping activity in between two striping activities (AN1 ON and OFF) for this pilot data analysis. All measurements were based on striping and driving distance as shown in Tables 4.1 and 4.2. The algorithm used for the pilot data analysis was:

$$\begin{aligned} &Striping\ Dist.\ (mile) = Total\ Odometer \\ &\quad Reading Dist. - (Yard\ to\ Site\ Dist. + Non- \\ &\quad Striping\ Dist. + \text{Site}\ to\ Yard\ Dist.) \end{aligned}$$

The algorithm only counted distance between the rear master control switch AN1 ON and OFF because of limited availability of other data. However, it was

TABLE 4.1
Fall 2011 Pilot Data Summary for Centerline Striping Trucks

		Crawfordsville (61457)				Greenfield (63597)			
Week	**Striping Date**	**Odometer reading (Miles)**	**Striping dist. (Miles)**	**Yard-site-yard(Mile)**	**Non-striping dist. (Miles)**	**Odometer reading (Miles)**	**Striping dist. (Miles)**	**Yard-site-yard(Mile)**	**Non-striping dist. (Miles)**
1	Tue, 09/20/2011	130	22	91	17	158	36	50	72
	Wed, 09/21/2011					149	90	58	1
	Thur, 09/22/2011	113	45	49	19	123	57	66	0
	Fri, 09/23/2011								
	Sat, 09/24/2011								
	Sun, 09/25/2011								
	Mon, 09/26/2011	104	17	87	0				
2	Tue, 09/27/2011								
	Wed, 09/28/2011								
	Thur, 09/29/2011					125	41	41	43
	Fri, 09/30/2011								
	Sat, 10/01/2011								
	Sun, 10/02/2011								
	Mon, 10/03/2011					36	34	2	0
3	Tue, 10/04/2011	73	18	55	0				
	Wed, 10/05/2011					120	57	60	3
	Thur, 10/06/2011	138	66	58	14				
	Fri, 10/07/2011								
	Sat, 10/08/2011								
	Sun, 10/09/2011								
	Mon, 10/10/2011								
4	Tue, 10/11/2011	146	51	93	2	152	101	51	0
	Wed, 10/12/2011								
	Thur, 10/13/2011								
	Fri, 10/14/2011								
	Sat, 10/15/2011								
	Sun, 10/16/2011								
	Mon, 10/17/2011	78	6	71	1				
5	Tue, 10/18/2011								
	Wed, 10/19/2011								
	Thur, 10/20/2011								
	Fri, 10/21/2011								
	Sat, 10/22/2011								
	Sun, 10/23/2011								
	Mon, 10/24/2011	73	2	61	10				
6	Tue, 10/25/2011	54	10	43	1				
	Wed, 10/26/2011								
	Thur, 10/27/2011								
	Fri, 10/28/2011								
	Sat, 10/29/2011								
	Sun, 10/30/2011								
	Mon, 10/31/2011								
7	Tue, 11/01/2011								
	Wed, 11/02/2011	154	23	65	66				
	Thur, 11/03/2011								
	Fri, 11/04/2011								
	Sat, 11/05/2011								
	Sun, 11/06/2011								
	Mon, 11/07/2011								

TABLE 4.1
(Continued)

		Crawfordsville (61457)				Greenfield (63597)			
Week	**Striping Date**	**Odometer reading (Miles)**	**Striping dist. (Miles)**	**Yard-site-yard(Mile)**	**Non-striping dist. (Miles)**	**Odometer reading (Miles)**	**Striping dist. (Miles)**	**Yard-site-yard(Mile)**	**Non-striping dist. (Miles)**
8	Tue, 11/08/2011								
	Wed, 11/09/2011								
	Thur, 11/10/2011					154	4	79	71
	Fri, 11/11/2011								
	Sat, 11/12/2011								
	Sun, 11/13/2011								
	Mon, 11/14/2011								
9	Tue, 11/15/2011	151	3	106	42				
	Wed, 11/16/2011								
	Thur, 11/17/2011								
	Fri, 11/18/2011								
	Sat, 11/19/2011								
	Sun, 11/20/2011								
	Mon, 11/21/2011								

NOTE: November11, 2011, was the last day of centerline striping operation.

TABLE 4.2
Fall 2011 Pilot Data Summary for Edgeline Striping Trucks

		Crawfordsville (61249)				Greenfield (63759)			
Week	**Striping Date**	**Odometer reading (Miles)**	**Striping dist. (Miles)**	**yard-site-yard(Mile)**	**Non-striping dist. (Miles)**	**Odometer reading (Miles)**	**Striping dist. (Miles)**	**yard-site-yard(Mile)**	**Non-striping dist. (Miles)**
1	Tue, 09/20/2011					170	76	93	1
	Wed, 09/21/2011	156	42	58	56				
	Thur, 09/22/2011								
	Fri, 09/23/2011								
	Sat, 09/24/2011								
	Sun, 09/25/2011								
	Mon, 09/26/2011					141	33	73	35
2	Tue, 09/27/2011								
	Wed, 09/28/2011								
	Thur, 09/29/2011								
	Fri, 09/30/2011								
	Sat, 10/01/2011								
	Sun, 10/02/2011								
	Mon, 10/03/2011								
3	Tue, 10/04/2011					61	57	3	1
	Wed, 10/05/2011	46	16	17	13				
	Thur, 10/06/2011	112	55	57	0	159	116	8	35
	Fri, 10/07/2011					159	101	35	23
	Sat, 10/08/2011								
	Sun, 10/09/2011								
	Mon, 10/10/2011								
4	Tue, 10/11/2011					121	23	96	2
	Wed, 10/12/2011	154	53	101	0	148	107	39	2
	Thur, 10/13/2011								
	Fri, 10/14/2011	147	37	110	0	41	23	15	3
	Sat, 10/15/2011								
	Sun, 10/16/2011								
	Mon, 10/17/2011								

NOTE: October 14, 2011, was the last day of edgeline striping operation.

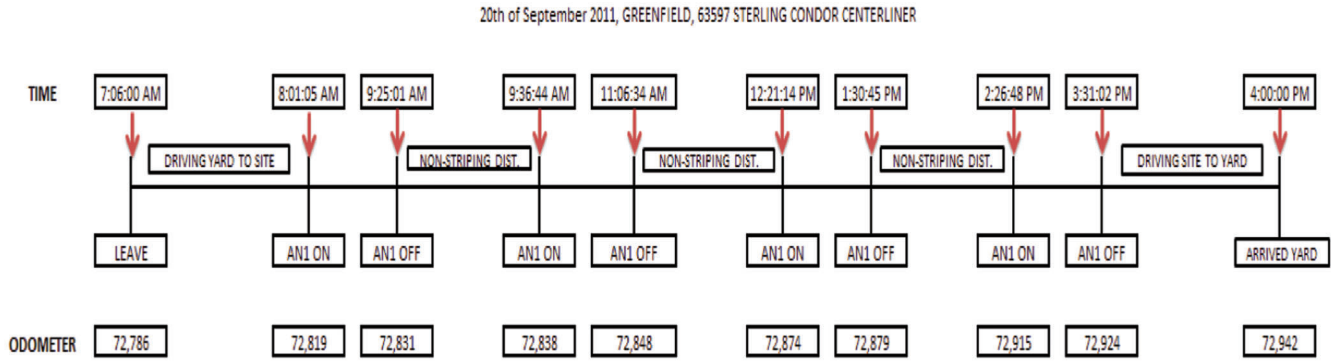

Figure 4.1 Centerline striping trucks—Greenfield (63597)—Sept 20, 2011.

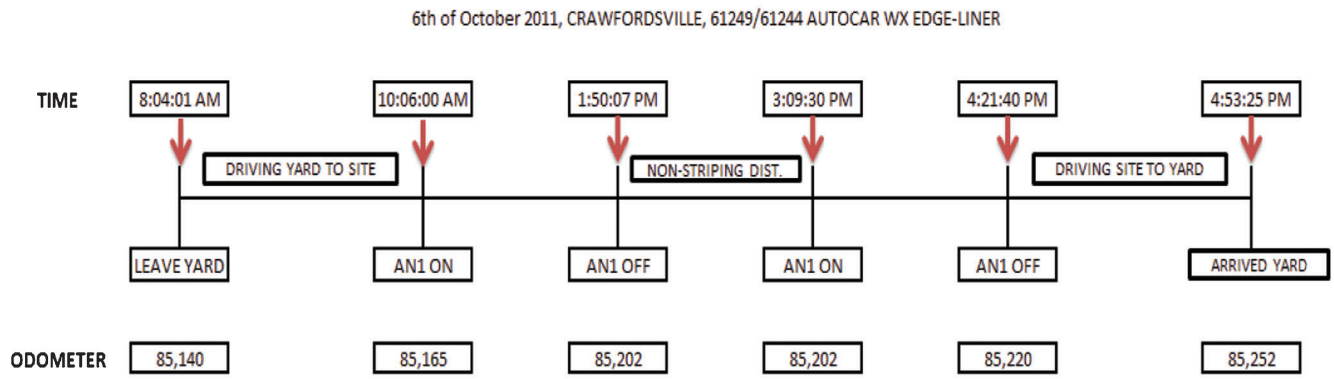

Figure 4.2 Edgeline striping trucks—Crawfordsville (61249/61244)—Oct 6, 2011.

initially presumed that daily measurement of driving and striping distance would provide a good picture for striping truck utilization and productivity comparison. Unfortunately a shortfall of this assumption is that the truck operators would turn on, but fail to turn off the rear master switch while they were driving between sites. Thus, total striping distance would be exaggerated. This algorithm has been updated for 2013 striping season data collection after telematics device configuration updates as shown in Tables 3.1 and 3.2.

Table 4.3 presents a summary of the productivity analysis of striping trucks based on the 2011 pilot data. Several significant differences between the two districts have been found. The Greenfield district operation analysis indicates higher productivity than the Crawfordsville district with regards to striping distance per

TABLE 4.3
Fall 2011 Pilot Data Productivity Analysis Summary

Centerline Striping Trucks	Crawfordsville (61457)	Greenfield (63597)	Crawfordsville (61249)	Greenfield (63759)
First date for data input	Tuesday, 09-20-2011	Tuesday, 09-20-2011	Wednesday, 09-21-2011	Tuesday, 09-20-2011
Last date for data input	Tuesday, 11-15-2011	Thursday, 11-10-2011	Friday, 10-14-2011	Friday, 10-14-2011
Days of operation	11 days	8 days	5 days	8 days
Days of non-operation	52 days	55 days	58 days	55 days
Total mileage of striping distance	263 miles	420 miles	203 miles	536 miles
Total mileage of start-site-finish	779 miles	407 miles	343 miles	362 miles
Total mileage of non-striping between striping operations	172 miles	190 miles	69 miles	102 miles
Total mileage based on odometer reading	1214 miles	1017 miles	615 miles	1000 miles
Average striping mileage per operation day	23.9 miles/day	52.5 miles/day	40.6 miles/day	67 miles/day
Average driving mileage start-to-finish per operation day	70.81 miles/day	50.88 miles/day	68.6 miles/day	45.25 miles/day
Average non-striping mileage between striping operations	15.64 miles/day	23.75 miles/day	13.8 miles/day	12.75 miles/day
Average driving mileage per operation day	110.36 miles/day	127.13 miles/day	123 miles/day	125 miles/day

day. However, overall average daily driving distances in both districts are almost equivalent. Therefore, it can be assumed that average work hours in both districts are similar. In addition, there are two drawbacks in these analyses. (1) Data configuration: Crews may turn on the rear striping control unit (data is recorded as AN1) while they are not striping. This operational pattern can affect productivity analysis because it's difficult to identify the difference between actual striping distance and driving without striping while AN1 is ON. This issue has been resolved by reconfiguring the telematics device and updating the algorithm for Task 3. (2) Data collection period: Because of the limited Task 2 data collection period at the end of the fall 2011 striping operation, insufficient amount of data was obtained to determine striping operation productivity.

5. 2012 DATA COLLECTION, ANALYSIS, EVALUATION, AND VALIDATION

Updated and re-configured data collection devices were implemented for the new season. The striping season was presumably between Sunday, April 01, 2012 and Friday, November 30, 2012. The study focused on four main striping trucks as shown in Tables 5.1 and 5.2. The following analyses were conducted to validate the use of telematics.

- Productivity analysis (Section 5.1)
- Utilization analysis (Section 5.2)
- Idling analysis (Section 5.3)
- Comparison analysis between Work Management System (WMS) and data collection (Section 5.4)
- Volume of painting analysis (Section 5.5)
- Geospatial operation tracking and striping speed analysis (Section 5.5)

5.1 Productivity Analysis

Both Crawfordsville and Greenfield districts operate a roadway striping fleet consisting of a centerline striping truck, an edgeline striping truck, and supporting vehicles. Productivity analysis primarily focuses on two types of striping trucks in each district. Telematics devices collected and transmitted data to the web server. Productivity in this study is defined as striping distance in an operation day and production rate is measured in ratios between striping distance and total distance for a specific period. Definitions for other distance data are as follows:

- *Total Distance:* This is the daily driving distance (mileage) of each striping truck. Total Distance is measured by the difference between the odometer readings of the striping truck "when engine is started for the first time at the beginning of a day" and "when engine is stopped for the last time at the end of a day".
- *Striping Distance:* This is daily striping distance (mileage) of each striping truck. Striping distance is measured by the difference between ON and OFF of data signals from each sensor as indicated in Table 3.2. The GT telematics only measures linear driving distance while striping, thus a painting operation that simultaneously paints double solid or solid and skipped lines together, is measured as a single linear striping distance, not an accumulated striping distance.
- *Start-to-Site Distance (District Yard to Work Site Distance):* This is the daily traveling distance of each striping truck from district (it can be sub-district or job site overnight parking) yard to work site. Start-to-site distance is measured by the difference between the odometer readings of "when the truck left yard for the first time at the beginning of a day" and "when striping is started for the first time in a day".
- *Site-to-Finish Distance (Work Site to District Yard Distance):* This is the daily traveling distance of each striping truck from work site to district (it can be sub-district or job site overnight parking) yard. Site-to-finish distance is measured by the difference between the odometer readings of "when striping is finished" and "when the truck has arrived at the yard at the end of a day operation".
- *Non-Striping Distance:* This is the transition driving distance between two different site locations. Non-striping distance is measured by the following Equation 5.1:

$$\begin{aligned} &Non-Striping\ Dist. = Total\ Dist. - \\ &\quad \{Striping\ Dist. + Start-to- \\ &\quad site\ Dist. + Site-to-finish\ Dist.\} \end{aligned} \tag{Eq. 5.1}$$

The daily distance data can be extracted from the "*Gauge Smart Hub Website*" (hereafter; website). Instructions and further details of the website are detailed in the manual, Appendix I. The website is able to generate reports as shown in Tables 5.1 and 5.2. The report is titled as "Striping Report +" and located under the "Reports" main tab, under "Off Road" sub tab and under the "Specialty" tab. Figure 5.1 is an example demonstrating a summary of daily striping data. Striping data including AN2, AN3, D3 and D4 are identified in a striping detail report from the website.

Tables 5.3 through 5.12 show overall productivity data summaries for all striping trucks and supporting vehicles. A total of 244 calendar days in the 2012 striping operation season are counted from April 1 to November 30, 2012. Operation days varied in each district and for each truck. Non-operation days significantly exceeded operation days regardless of district location and type of striping truck. Overall striping distances from all striping trucks were measured to be within 15 percent difference range. One notable aspect of the production schedule is that Greenfield district began its striping operation almost a month later than Crawfordsville district. Each district's operation schedule is currently autonomously operated and there is no mutual interaction between the two districts. To analyze productivity between the two districts, the following assumptions were made:

- No weather effect
- Striping season begins and ends on the same day in both districts regardless of their actual schedule in 2012 striping season.

TABLE 5.1
2012 Centerline Striping Trucks Daily Distance (Data from April 10, 2012, to November 18, 2012)

Work Schedule		Crawfordsville61457 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)					Greenfield63597 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)				
Week	Date	Start to Site	Striping	Non-Striping	Site to Finish	Total	Start to Site	Striping	Non-Striping	Site to Finish	Total
16	4/10/2012	29	11	12	23	76	0	0	0	0	0
	4/11/2012	27	16	15	23	81	0	0	0	0	0
	4/12/2012	24	19	35	30	108	0	0	0	0	0
	Week Total	80	47	62	76	265	0	0	0	0	0
	Week %	30%	18%	23%	29%	100%	0%	0%	0%	0%	0%
18	4/24/2012	28	23	9	0	61	0	0	0	0	0
	4/26/2012	21	24	18	5	69	0	0	0	0	0
	Week Total	50	48	27	6	130	0	0	0	0	0
	Week %	38%	37%	21%	4%	100%	0%	0%	0%	0%	0%
19	5/1/2012	10	12	6	27	56	0	0	0	0	0
	5/2/2012	74	3	4	65	146	0	0	0	0	0
	5/3/2012	66	13	25	43	148	0	0	0	0	0
	Week Total	151	28	35	136	350	0	0	0	0	0
	Week %	43%	8%	10%	39%	100%	0%	0%	0%	0%	0%
20	5/9/2012	36	24	12	5	77	24	19	51	13	107
	5/10/2012	6	25	21	34	86	32	19	27	1	80
	Week Total	42	50	33	38	163	56	39	78	14	187
	Week %	26%	30%	20%	24%	100%	30%	21%	42%	7%	100%
21	5/14/2012	41	25	16	38	120	38	23	18	51	129
	5/15/2012	37	25	55	47	164	23	22	54	22	120
	5/16/2012	25	24	60	6	115	5	38	13	1	58
	5/17/2012	18	12	15	48	94	26	19	47	48	140
	Week Total	121	86	147	140	494	93	103	131	121	447
	Week %	25%	17%	30%	28%	100%	21%	23%	29%	27%	100%
22	5/21/2012	0	0	0	0	0	41	18	39	31	128
	5/22/2012	0	0	0	0	0	17	22	59	16	114
	5/23/2012	0	0	0	0	0	19	49	16	24	108
	5/24/2012	0	0	0	0	0	30	27	2	24	83
	Week Total	0	0	0	0	0	107	116	116	95	434
	Week %	0%	0%	0%	0%	0%	25%	27%	27%	22%	100%
23	5/29/2012	0	0	0	0	0	34	22	5	34	96
	5/30/2012	27	22	18	30	97	38	46	(1)	50	133
	5/31/2012	73	17	15	46	151	39	12	62	56	169
	Week Total	100	39	33	75	247	111	80	66	141	399
	Week %	40%	16%	13%	31%	100%	28%	20%	17%	35%	100%
24	6/4/2012	0	0	0	0	0	17	24	32	15	89
	6/5/2012	24	17	63	40	144	4	25	38	29	95
	6/6/2012	81	18	26	72	197	15	23	33	24	95
	6/7/2012	42	21	30	36	128	26	24	30	44	125
	Week Total	147	55	119	148	470	62	96	132	113	404
	Week %	31%	12%	25%	31%	100%	15%	24%	33%	28%	100%
25	6/11/2012	0	0	0	0	0	17	13	39	23	92
	6/12/2012	0	0	0	0	0	17	13	41	39	110
	6/13/2012	78	21	32	52	183	37	10	39	34	120
	6/14/2012	17	14	34	24	89	1	19	7	15	42
	Week Total	95	35	66	75	271	71	55	126	111	363
	Week %	35%	13%	24%	28%	100%	20%	15%	35%	31%	100%

TABLE 5.1
(Continued)

Work Schedule		Crawfordsville61457 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)					Greenfield63597 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)				
Week	**Date**	**Start to Site**	**Striping**	**Non-Striping**	**Site to Finish**	**Total**	**Start to Site**	**Striping**	**Non-Striping**	**Site to Finish**	**Total**
26	6/18/2012	0	0	0	0	0	14	16	34	1	65
	6/19/2012	0	0	0	0	0	18	20	25	50	112
	6/20/2012	59	3	4	0	65	36	15	23	55	129
	6/21/2012	0	11	28	66	105	3	16	65	40	124
	6/24/2012	1	15	0	0	16	0	0	0	0	0
	Week Total	59	29	32	66	186	71	66	147	145	430
	Week %	32%	15%	17%	35%	100%	17%	15%	34%	34%	100%
27	6/25/2012	0	45	80	13	138	40	6	6	28	80
	6/26/2012	4	45	129	2	181	5	47	21	5	78
	6/27/2012	16	38	53	0	107	15	52	49	13	129
	6/28/2012	0	12	52	30	93	41	11	23	33	108
	Week Total	19	139	314	46	518	102	116	99	78	395
	Week %	4%	27%	61%	9%	100%	26%	29%	25%	20%	100%
28	7/2/2012	46	14	31	45	136	2	13	58	9	83
	7/3/2012	34	8	1	32	76	0	0	0	0	0
	7/5/2012	0	0	0	0	0	37	10	36	42	125
	Week Total	80	22	32	77	212	39	23	94	51	207
	Week %	38%	10%	15%	36%	100%	19%	11%	45%	25%	100%
29	7/9/2012	13	24	41	63	141	43	14	68	65	190
	7/10/2012	0	0	0	0	0	23	12	53	47	136
	7/11/2012	0	0	0	0	0	67	13	36	18	135
	7/12/2012	32	24	24	36	116	0	0	0	0	0
	7/14/2012	0	0	0	0	0	9	6	29	13	57
	Week Total	45	47	65	100	257	142	45	186	144	517
	Week %	17%	18%	25%	39%	100%	27%	9%	36%	28%	100%
30	7/16/2012	0	0	0	0	0	61	10	43	62	176
	7/17/2012	47	27	31	67	172	18	12	129	52	211
	7/18/2012	64	25	41	43	172	61	2	49	3	115
	7/19/2012	84	17	28	42	171	12	15	5	94	126
	Week Total	195	69	100	151	515	152	40	225	212	628
	Week %	38%	13%	19%	29%	100%	24%	6%	36%	34%	100%
31	7/24/2012	35	35	17	51	139	0	0	0	0	0
	7/25/2012	56	36	11	53	155	29	26	25	28	108
	7/26/2012	56	31	25	45	158	30	30	43	42	145
	Week Total	146	102	53	150	451	60	56	68	70	253
	Week %	32%	23%	12%	33%	100%	24%	22%	27%	28%	100%
32	7/30/2012	0	0	0	0	0	98	4	13	24	140
	7/31/2012	66	14	1	63	144	47	41	16	47	151
	8/1/2012	76	12	39	67	195	0	0	0	0	0
	8/2/2012	0	0	0	0	0	52	29	30	35	146
	8/3/2012	0	0	0	0	0	39	5	6	26	76
	Week Total	142	26	41	131	339	236	79	66	133	514
	Week %	42%	8%	12%	39%	100%	46%	15%	13%	26%	100%
33	8/6/2012	46	43	7	57	153	29	20	6	0	55
	8/7/2012	60	18	3	56	137	0	19	124	0	143
	8/8/2012	3	0	0	4	7	0	30	36	119	186
	Week Total	109	61	10	117	297	29	70	166	119	384
	Week %	37%	21%	3%	39%	100%	8%	18%	43%	31%	100%

TABLE 5.1
(Continued)

Work Schedule		Crawfordsville61457 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)					Greenfield63597 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)				
Week	Date	Start to Site	Striping	Non-Striping	Site to Finish	Total	Start to Site	Striping	Non-Striping	Site to Finish	Total
34	8/13/2012	0	0	0	0	0	49	3	33	4	89
	8/14/2012	0	0	0	0	0	22	24	142	0	188
	8/15/2012	0	0	0	0	0	0	22	139	0	160
	8/16/2012	0	0	0	0	0	0	26	35	41	102
	Week Total	0	0	0	0	0	70	74	349	45	539
	Week %	0%	0%	0%	0%	0%	13%	14%	65%	8%	100%
35	8/20/2012	0	0	0	0	0	43	3	35	0	81
	8/21/2012	0	0	0	0	0	0	38	104	2	145
	8/22/2012	0	0	0	0	0	0	16	143	0	160
	8/23/2012	26	15	62	36	140	2	22	149	1	175
	8/24/2012	0	0	0	0	0	3	10	73	23	108
	8/25/2012	0	0	0	0	0	28	7	11	23	69
	8/26/2012	32	4	12	0	48	0	0	0	0	0
	Week Total	58	19	73	36	187	76	97	514	49	737
	Week %	31%	10%	39%	19%	100%	10%	13%	70%	7%	100%
36	8/27/2012	3	19	99	0	122	0	0	0	0	0
	8/28/2012	0	20	118	3	141	0	0	0	0	0
	8/29/2012	7	12	142	0	161	0	0	0	0	0
	8/30/2012	29	13	50	34	126	0	0	0	0	0
	Week Total	39	64	410	37	550	0	0	0	0	0
	Week %	7%	12%	75%	7%	100%	0%	0%	0%	0%	0%
37	9/4/2012	29	13	12	31	85	96	11	48	63	217
	9/5/2012	28	21	1	42	91	37	8	75	19	138
	9/6/2012	29	37	10	25	101	19	11	103	24	158
	Week Total	86	71	23	98	277	151	30	226	105	513
	Week %	31%	26%	8%	35%	100%	30%	6%	44%	21%	100%
38	9/11/2012	48	17	24	48	137	0	0	0	0	0
	9/12/2012	37	41	8	41	127	25	8	93	32	158
	9/13/2012	0	0	0	0	0	36	7	57	33	133
	Week Total	85	59	32	89	265	61	15	150	64	291
	Week %	32%	22%	12%	34%	100%	21%	5%	52%	22%	100%
39	9/17/2012	0	0	0	0	0	23	8	59	30	119
	9/18/2012	35	11	39	52	137	64	12	20	65	161
	9/19/2012	63	8	13	74	158	29	24	18	35	107
	9/20/2012	45	26	25	10	106	25	5	49	43	123
	9/21/2012	0	0	0	0	0	40	10	55	20	126
	Week Total	143	44	78	136	401	181	59	201	193	635
	Week %	36%	11%	19%	34%	100%	29%	9%	32%	30%	100%
40	9/24/2012	0	0	0	0	0	38	4	50	17	109
	9/28/2012	0	0	0	0	0	28	16	24	23	91
	Week Total	0	0	0	0	0	66	21	74	40	200
	Week %	0%	0%	0%	0%	0%	33%	10%	37%	20%	100%
41	10/1/2012	45	3	0	55	104	57	17	30	70	175
	Week Total	45	3	0	55	104	57	17	30	70	175
	Week %	44%	3%	0%	53%	100%	32%	10%	17%	40%	100%
42	10/9/2012	36	5	1	40	83	32	0	2	31	65
	10/10/2012	0	0	0	0	0	41	0	1	33	76
	10/11/2012	41	7	2	36	86	0	0	0	0	0
	Week Total	77	12	4	76	169	73	0	4	64	141
	Week %	46%	7%	2%	45%	100%	52%	0%	3%	46%	100%

TABLE 5.1
(Continued)

Work Schedule		Crawfordsville61457 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)					Greenfield63597 Centerliner STERLING Condor LCF Striping TruckDistance Unit (Miles)				
Week	Date	Start to Site	Striping	Non-Striping	Site to Finish	Total	Start to Site	Striping	Non-Striping	Site to Finish	Total
43	10/15/2012	54	4	2	21	82	25	16	10	23	74
	10/16/2012	0	4	63	73	139	0	0	0	0	0
	10/17/2012	46	2	2	50	99	0	0	0	0	0
	10/18/2012	34	1	(0)	35	70	0	0	0	0	0
	Week Total	135	10	67	179	391	25	16	10	23	74
	Week %	34%	3%	17%	46%	100%	34%	21%	13%	32%	100%
44	10/22/2012	49	28	4	63	145	0	0	0	0	0
	10/23/2012	0	0	0	0	0	0	0	(0)	61	61
	10/24/2012	63	19	10	41	133	0	6	51	6	63
	10/25/2012	0	0	0	0	0	50	6	59	0	116
	10/26/2012	0	0	0	0	0	1	2	16	26	45
	Week Total	112	48	14	104	277	52	14	126	92	284
	Week %	40%	17%	5%	37%	100%	18%	5%	44%	32%	100%
45	11/1/2012	0	0	0	0	0	40	34	15	39	128
	Week Total	0	0	0	0	0	40	34	15	39	128
	Week %	0%	0%	0%	0%	0%	31%	27%	12%	30%	100%
47	11/18/2012	0	0	0	0	0	28	6	6	37	78
	Week Total	0	0	0	0	0	28	6	6	37	78
	Week %	0%	0%	0%	0%	0%	36%	8%	8%	48%	100%
	Total	2363	1,211	1,872	2,342	7,788	2211	1,368	3,405	2,371	9,355
	Total %	30%	16%	24%	30%	100%	24%	15%	36%	25%	100%

- All geographical conditions are no effect.
- All other conditions are no effect.

Table 5.3 presents a summary of daily operation data from two centerline striping trucks. The Crawfordsville centerline truck operated 66 days and the Greenfield district truck operated 80 days. Several findings are as follows:

- Although Crawfordsville centerline striping activity began a month prior to Greenfield, Greenfield operated 14 additional days than Crawfordsville.
- Greenfield striped 157 more centerline miles than Crawfordsville.
- Greenfield's centerline striping truck traveled 1,533 more miles between striping sites (non-striping distance) during daily operation.
- Greenfield's centerline striping truck traveled 1,567 more miles than Crawfordsville's during the entire operation period.

Table 5.4 presents a summary of production rates of two centerline striping trucks based on the number of operation days. Productivity in this study is primarily based on striping mileage (distances) per operation day. In addition, the results of truck non-productivity analysis are summarized in Table 5.4 with respect to average mileage per operation day of each centerline truck. Several findings are as follows:

- Crawfordsville's centerline truck striped an average 1.2 more miles than the Greenfield truck
- Crawfordsville's centerline truck drove an average 1.1 more miles per day than Greenfield's.
- Crawfordsville's centerline truck drove an average 8.20 more start-to-site miles per day than the Greenfield truck
- Greenfield centerline truck drove an average 14.2 more non-striping miles per day.

Table 5.5 presents a summary of production rates of two the centerline striping trucks based on the number of calendar days (244 days). The results of truck productivity and non-productivity are summarized in Table 5.6 with respect to average mileage per calendar day of each centerline truck. Several findings are as follows:

- Greenfield's centerline truck striped an average 0.6 more miles than Crawfordsville's.
- Greenfield centerline truck drove an average 6.4 miles per day more than Crawfordsville.
- Crawfordsville centerline truck drove an average 0.6 more start-to-site miles per day.
- Greenfield centerline truck drove an average 6.3 more non-striping miles per day than the Crawfordsville truck.

Tables 5.6 and 5.7 presents a summary of daily activity from two edgeline striping trucks. The results of productivity analysis are summarized in terms of average mileage per day of each edgeline truck. The Crawfordsville edgeline truck operated only 46 days and the Greenfield truck operated only 44 days. Several findings are listed as follows:

TABLE 5.2
2012 Edgeline Striping Trucks Daily Distance (Data from April 10, 2012, to November 18, 2012)

Work Schedule		Crawfordsville61249 Edgeliner Autocar WX Striping TruckDistance Unit (Miles)					Greenfield63759 Edgeliner White GMC WX Xpeditor Striping TruckDistance Unit (Miles)				
Week	**Date**	**Start To Site**	**Striping**	**Non-Striping**	**Site to Finish**	**Total**	**Start To Site**	**Striping**	**Non-Striping**	**Site to Finish**	**Total**
16	4/9/2012	32	25	2	17	77	0	0	0	0	0
	Week Total	32	25	2	17	77	0	0	0	0	0
	Week %	42%	33%	2%	23%	100%	0%	0%	0%	0%	0%
17	4/17/2012	21	26	17	0	64	0	0	0	0	0
	4/18/2012	43	47	34	20	144	0	0	0	0	0
	Week Total	64	73	51	20	209	0	0	0	0	0
	Week %	31%	35%	24%	10%	100%	0%	0%	0%	0%	0%
19	5/3/2012	0	0	0	0	0	3	48	44	5	100
	Week Total	0	0	0	0	0	3	48	44	5	100
	Week %	0%	0%	0%	0%	0%	3%	48%	44%	5%	100%
20	5/10/2012	0	0	0	0	0	33	51	19	37	140
	Week Total	0	0	0	0	0	33	51	19	37	140
	Week %	0%	0%	0%	0%	0%	24%	36%	14%	26%	100%
21	5/14/2012	55	48	6	70	180	23	34	24	22	103
	5/15/2012	70	37	0	50	158	61	47	19	73	200
	5/16/2012	64	50	50	15	178	38	34	45	35	152
	5/17/2012	36	25	32	13	107	50	46	25	54	175
	Week Total	226	160	89	148	623	171	162	112	183	630
	Week %	36%	26%	14%	24%	100%	27%	26%	18%	29%	100%
22	5/21/2012	64	45	14	53	175	17	46	5	30	98
	5/22/2012	68	39	17	51	176	5	59	37	33	135
	5/23/2012	0	0	0	0	0	31	45	51	29	156
	5/24/2012	26	24	12	21	82	0	0	0	0	0
	Week Total	158	108	43	125	434	54	150	93	92	389
	Week %	36%	25%	10%	29%	100%	14%	38%	24%	24%	100%
23	5/31/2012	0	0	0	0	0	36	0	(0)	37	73
	Week Total	0	0	0	0	0	36	0	(0)	37	73
	Week %	0%	0%	0%	0%	0%	49%	1%	0%	50%	100%
24	6/4/2012	0	0	0	0	0	3	39	86	4	132
	6/5/2012	29	37	6	76	148	3	32	93	33	162
	6/6/2012	78	40	14	73	206	0	0	0	0	0
	6/7/2012	61	34	3	31	129	0	0	0	0	0
	Week Total	168	112	23	181	483	7	71	179	36	294
	Week %	35%	23%	5%	37%	100%	2%	24%	61%	12%	100%
25	6/11/2012	53	33	29	52	167	0	0	0	0	0
	6/12/2012	0	22	132	1	155	0	0	0	0	0
	6/17/2012	1	21	2	6	30	0	0	0	0	0
	Week Total	55	76	163	59	352	0	0	0	0	0
	Week %	15%	22%	46%	17%	100%	0%	0%	0%	0%	0%
26	6/18/2012	1	54	68	3	126	0	0	0	0	0
	6/19/2012	44	53	7	45	149	0	0	0	0	0
	Week Total	45	107	75	48	275	0	0	0	0	0
	Week %	16%	39%	27%	17%	100%	0%	0%	0%	0%	0%
27	6/26/2012	0	0	0	0	0	15	41	31	44	131
	6/27/2012	0	0	0	0	0	31	37	12	32	112
	6/28/2012	4	11	9	5	29	51	32	8	83	174
	Week Total	4	11	9	5	29	97	109	52	159	417
	Week %	15%	37%	30%	18%	100%	23%	26%	12%	38%	100%

TABLE 5.2
(Continued)

Work Schedule		Crawfordsville61249 Edgeliner Autocar WX Striping TruckDistance Unit (Miles)					Greenfield63759 Edgeliner White GMC WX Xpeditor Striping TruckDistance Unit (Miles)				
Week	Date	Start To Site	Striping	Non-Striping	Site to Finish	Total	Start To Site	Striping	Non-Striping	Site to Finish	Total
28	7/3/2012	25	18	0	23	66	77	41	32	57	207
	7/5/2012	35	38	16	45	134	0	0	0	0	0
	Week Total	60	56	16	68	200	77	41	32	57	207
	Week %	30%	28%	8%	34%	100%	37%	20%	15%	28%	100%
29	7/9/2012	21	53	23	25	122	27	29	21	34	110
	7/10/2012	29	36	35	37	138	16	39	21	23	99
	7/11/2012	37	47	27	47	158	3	54	14	30	101
	7/12/2012	48	32	2	55	138	0	0	0	0	0
	Week Total	135	168	88	165	557	46	123	55	87	311
	Week %	24%	30%	16%	30%	100%	15%	39%	18%	28%	100%
30	7/16/2012	30	25	6	2	63	29	10	3	8	50
	7/17/2012	0	0	0	0	0	8	49	96	0	153
	7/18/2012	0	0	0	0	0	0	46	90	1	137
	7/19/2012	0	0	0	0	0	21	52	42	2	117
	7/20/2012	0	0	0	0	0	4	25	7	17	54
	Week Total	30	25	6	2	63	62	182	238	28	510
	Week %	48%	39%	10%	3%	100%	12%	36%	47%	6%	100%
31	7/23/2012	0	0	0	0	0	31	10	9	0	50
	7/24/2012	0	0	0	0	0	1	48	74	7	129
	7/25/2012	0	0	0	0	0	0	33	95	2	131
	7/26/2012	0	0	0	0	0	6	23	97	1	127
	7/27/2012	0	0	0	0	0	1	17	60	18	96
	Week Total	0	0	0	0	0	39	131	336	27	534
	Week %	0%	0%	0%	0%	0%	7%	25%	63%	5%	100%
32	7/30/2012	0	0	0	0	0	26	2	15	25	68
	7/31/2012	70	25	2	95	192	0	0	0	0	0
	8/1/2012	63	44	4	64	175	17	24	146	4	190
	Week Total	133	68	6	160	366	42	26	160	29	258
	Week %	36%	19%	2%	44%	100%	16%	10%	62%	11%	100%
33	8/8/2012	3	1	2	3	9	0	0	0	0	0
	Week Total	3	1	2	3	9	0	0	0	0	0
	Week %	38%	8%	18%	36%	100%	0%	0%	0%	0%	0%
34	8/13/2012	31	3	3	30	67	0	0	0	0	0
	8/14/2012	43	42	17	51	153	0	0	0	0	0
	8/15/2012	46	45	30	25	147	0	0	0	0	0
	8/16/2012	28	21	0	25	74	26	24	56	23	129
	Week Total	149	111	50	131	441	26	24	56	23	129
	Week %	34%	25%	11%	30%	100%	20%	18%	44%	18%	100%
35	8/20/2012	43	9	0	27	80	30	49	22	28	129
	8/21/2012	0	0	0	0	0	16	21	89	17	143
	8/26/2012	49	3	2	0	54	0	0	0	0	0
	Week Total	92	12	2	27	134	46	70	111	45	273
	Week %	69%	9%	1%	20%	100%	17%	26%	41%	16%	100%
36	8/27/2012	0	28	113	0	141	0	0	0	0	0
	8/28/2012	8	23	137	0	167	19	34	47	16	117
	8/29/2012	2	33	93	19	147	23	17	74	23	137
	8/30/2012	2	25	10	31	68	0	0	0	0	0
	Week Total	12	109	353	50	523	42	51	121	39	254
	Week %	2%	21%	67%	10%	100%	16%	20%	48%	16%	100%

TABLE 5.2
(Continued)

Work Schedule		Crawfordsville61249 Edgeliner Autocar WX Striping TruckDistance Unit (Miles)					Greenfield63759 Edgeliner White GMC WX Xpeditor Striping TruckDistance Unit (Miles)				
Week	Date	Start To Site	Striping	Non-Striping	Site to Finish	Total	Start To Site	Striping	Non-Striping	Site to Finish	Total
38	9/10/2012	51	25	41	35	151	14	21	95	15	144
	9/11/2012	0	0	0	0	0	14	13	35	26	88
	9/13/2012	44	15	3	44	107	0	0	0	0	0
	Week Total	95	40	44	79	258	28	34	130	41	233
	Week %	37%	16%	17%	31%	100%	12%	15%	56%	18%	100%
39	9/17/2012	44	43	5	46	138	0	0	0	0	0
	9/18/2012	49	13	0	33	95	0	0	0	0	0
	Week Total	93	56	5	80	233	0	0	0	0	0
	Week %	40%	24%	2%	34%	100%	0%	0%	0%	0%	0%
40	9/28/2012	0	0	0	0	0	34	15	47	56	152
	Week Total	0	0	0	0	0	34	15	47	56	152
	Week %	0%	0%	0%	0%	0%	22%	10%	31%	37%	100%
41	10/4/2012	51	18	1	63	133	56	13	21	0	90
	Week Total	51	18	1	63	133	56	13	21	0	90
	Week %	38%	13%	1%	48%	100%	62%	14%	24%	0%	100%
43	10/15/2012	55	11	1	55	122	0	0	0	0	0
	Week Total	55	11	1	55	122	0	0	0	0	0
	Week %	45%	9%	1%	45%	100%	0%	0%	0%	0%	0%
45	11/2/2012	45	10	82	31	169	0	0	0	0	0
	Week Total	45	10	82	31	169	0	0	0	0	0
	Week %	27%	6%	48%	19%	100%	0%	0%	0%	0%	0%
46	11/8/2012	0	0	0	0	0	15	23	32	31	101
	11/9/2012	0	0	0	0	0	7	1	13	7	29
	Week Total	0	0	0	0	0	22	24	45	38	129
	Week %	0%	0%	0%	0%	0%	17%	18%	35%	29%	100%
47	11/18/2012	0	0	0	0	0	26	21	4	27	79
	Week Total	0	0	0	0	0	26	21	4	27	79
	Week %	0%	0%	0%	0%	0%	33%	27%	5%	34%	100%
48	11/20/2012	0	0	0	0	0	27	0	3	26	56
	Week Total	0	0	0	0	0	27	0	3	26	56
	Week %	0%	0%	0%	0%	0%	48%	1%	5%	46%	100%
	Total	1706	1,357	1,110	1,518	5,690	975	1,348	1,860	1,073	5,257
	Total %	30%	24%	20%	27%	100%	19%	26%	35%	20%	100%

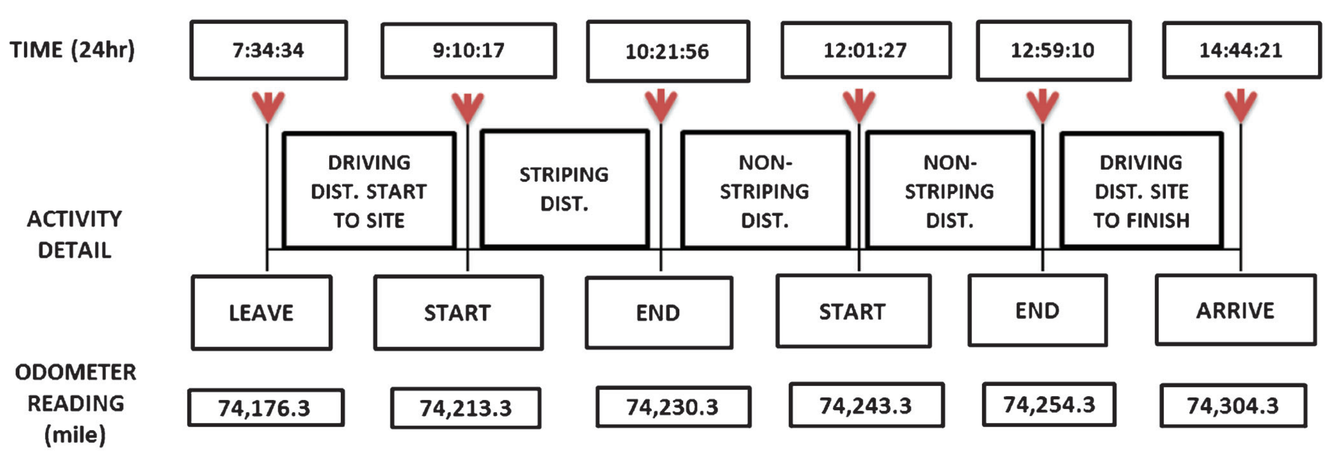

Figure 5.1 Centerline striping truck—Greenfield (63597)—May 14, 2012.

TABLE 5.3
Centerline Striping Trucks Productivity Analysis: 2012 Summary Data

Centerline Striping Trucks	Crawfordsville (61457)	Greenfield (63597)
First date for striping season	Sunday, April 01, 2012	Sunday, April 01, 2012
Last date for striping season	Friday, November 30, 2012	Friday, November 30, 2012
First date for data input	Tuesday, April 10, 2012	Wednesday, May 09, 2012
Last date for data input	Wednesday, October 24, 2012	Sunday, November 18, 2012
Total striping operation days	66 days	80 days
Total non-operation days	178 days	164 days
Total calendar days	244 days	244 days
Total mileage of striping distance	1,211 miles	1,368 miles
Total mileage of Start-to-Site	2,363 miles	2,211 miles
Total mileage of Site-to-Finish	2,342 miles	2,371 miles
Total mileage of non-striping	1,872 miles	3,405 miles
Total mileage based on Odometer reading	7,788 miles	9,355 miles

- Crawfordsville edgeline striping activity began a month prior to Greenfield centerline activity, and operated 2 additional days.
- Crawfordsville's edgeline operation covered 433 more miles than Greenfield's (8 percent greater travel mileage).
- Crawfordsville's edgeline operation covered 9 miles more than Greenfield's.
- Average striping mileage productivity in both districts is less than 30 percent of total driving mileage.
- Crawfordsville's edgeline truck has an average 4.2 more total driving miles per day than Greenfield's.
- Greenfield's edgeline truck drove an average 1.1 more striping miles than Crawfordsville.
- Crawfordsville's edgeline truck drove an average 14.9 more Start-to-Site miles per day.
- Greenfield's edgeline truck drove an average 18.2 more non-striping miles per day.

Tables 5.4 and 5.7 are based only on operation days for the 2012 striping season productivity analysis. The results indicate that less than 16 percent of total distance was used for centerline striping and approximately 25 percent of total distance was used for edgeline striping. It is obvious that nonproductive distances such as site-to-start, site-to-finish, and non-striping need to be minimized in order to improve overall productivity.

Ratios between Operation Days and Calendar Days in Tables 5.5 and 5.8 indicate that only approximately 20 percent of total calendar days have been used for the edgeline striping operation and only 27 percent and 33 percent of total calendar days have been used for the centerline operation. Average striping distance is less than 6 miles per calendar days. The results are similar between both districts. Low productivity per a calendar day indicates low utilization of fleet. Fleet utilization is further explained in Section 5.2.

Supporting vehicle productivity analysis was excluded in the final report because it was not distinctive whether distances for the supporting vehicles were productive operation or nonproductive operation. The current data is not able to be analyzed because the initial telematics configuration was not set up to collect supporting vehicle productivity data.

5.2 Utilization Analysis

Utilization is defined in this study as the ratio between the number of operation days and available days in a month. The ratio simply indicates the frequency of striping truck utilization within a monthly period. The higher ratio (percent) in a district, the more use of a striping truck the district operates regardless of striping productivity.

Utilization analysis uses three types of days including operation days, calendar days and normal week days

TABLE 5.4
Centerline Striping Trucks Productivity Analysis: 2012 Operation Days

	Crawfordsville (61457)		Greenfield (63597)	
Description	Production Rate	Miles/Total Miles	Production Rate	Miles/Total Miles
Average striping mileage per operation day	18.3 miles/day	15.55%	17.1 miles/day	14.62%
Average driving mileage Start-to-Site per striping operation day	35.8 miles/day	30.34%	27.6 miles/day	23.63%
Average driving mileage Site-to-Finish per striping operation day	35.5 miles/day	30.07%	29.6 miles/day	25.34%
Average non-striping mileage per striping operation day	28.4 miles/day	24.04%	42.6 miles/day	36.40%
Average total driving mileage per striping operation day	118.0 miles/day	100.00%	116.9 miles/day	100.00%

TABLE 5.5
Centerline Striping Trucks Productivity Analysis: 2012 Calendar Days

Description	Crawfordsville (61457)		Greenfield (63597)	
	Production Rate	Operation/Calendar Days	Production Rate	Operation/Calendar Days
Average striping mileage per calendar day	5.0 miles/day	27%	5.6 miles/day	33%
Average driving mileage Start-to-Site per calendar day	9.7 miles/day	27%	9.1 miles/day	33%
Average driving mileage Site-to-Finish per calendar day	9.6 miles/day	27%	9.7 miles/day	33%
Average non-striping mileage per calendar day	7.7 miles/day	27%	14.0 miles/day	33%
Average total driving mileage per calendar day	31.9 miles/day	27%	38.3 miles/day	33%

TABLE 5.6
Edgeline Striping Trucks Productivity Analysis: Summary Data

Description	Crawfordsville (61249)	Greenfield (63759)
First date for striping season	Sunday, April 01, 2012	Sunday, April 01, 2012
Last date for striping season	Friday, November 30, 2012	Friday, November 30, 2012
First date for data input	Monday, April 09, 2012	Thursday, May 03, 2012
Last date for data input	Friday, November 02, 2012	Tuesday, November 20, 2012
Total striping operation days	46 days	44 days
Total non-operation days	198 days	200 days
Total calendar days	244 days	244 days
Total mileage of striping distance	1,357 miles	1,348 miles
Total mileage of Start-to-Site	1,706 miles	975 miles
Total mileage of Site-to-Finish	1,518 miles	1,073 miles
Total mileage of non-striping	1,110 miles	1,860 miles
Total mileage based on Odometer reading	5,690 miles	5,257 miles

TABLE 5.7
Edgeline Striping Trucks Productivity Analysis: Operation Days

Description	Crawfordsville (61249)		Greenfield (63759)	
	Production Rate	Miles/Total Miles	Production Rate	Miles/Total Miles
Average striping mileage per operation day	29.5 miles/day	23.85%	30.6 miles/day	25.64%
Average driving mileage Start-to-Site per striping operation day	37.1 miles/day	29.98%	22.2 miles/day	18.55%
Average driving mileage Site-to-Finish per striping operation day	33.0 miles/day	26.68%	24.4 miles/day	20.41%
Average non-striping mileage per striping operation day	24.1 miles/day	19.51%	42.3 miles/day	35.38%
Average total driving mileage per striping operation day	123.7 miles/day	100.00%	119.5 miles/day	100.00%

TABLE 5.8
Edgeline Striping Trucks Productivity Analysis: Calendar Days

Description	Crawfordsville (61249) Production Rate	Crawfordsville (61249) Operation/Calendar Days	Greenfield (63759) Production Rate	Greenfield (63759) Operation/Calendar Days
Average striping mileage per calendar day	5.6 miles/day	19%	5.5 miles/day	18%
Average driving mileage Start-to-Site per calendar day	7.0 miles/day	19%	4.0 miles/day	18%
Average driving mileage Site-to-Finish per calendar day	6.2 miles/day	19%	4.4 miles/day	18%
Average non-striping mileage per calendar day	4.5 miles/day	19%	7.6 miles/day	18%
Average total driving mileage per calendar day	23.3 miles/day	19%	21.5 miles/day	18%

TABLE 5.9
Striping Trucks Utilization Analysis (Crawfordsville): 2012 Operation, Calendar & Week Days

Crawfordsville Striping Operation Month in 2012	Calendar Days	Week Days	Operation Days: Operation Days Centerline (61457)	Operation Days: Operation Days Edgeline (61249)	Calendar Days: Operation Days/ Calendar Days Centerline (61457)	Calendar Days: Operation Days/Calendar Days Edgeline (61249)	Week Days: Operation Days/Week Days Centerline (61457)	Week Days: Operation Days/Week Days Edgeline (61249)
	Number of Days							
April	30	21	5	3	17%	10%	24%	14%
May	31	23	11	7	35%	23%	48%	30%
Jun	30	21	12	9	40%	30%	57%	43%
July	31	22	11	8	35%	26%	50%	36%
August	31	23	10	12	32%	39%	43%	52%
September	30	20	8	4	27%	13%	40%	20%
October	31	23	9	2	29%	6%	39%	9%
November	30	22	0	1	0%	3%	0%	5%
Total	244	175	66	46	27%	19%	38%	26%

TABLE 5.10
Striping Trucks Utilization Analysis (Greenfield): 2012 Operation, Calendar & Week Days

Greenfield Striping Operation Month in 2012	Calendar Days	Week Days	Operation Days: Operation Days Centerline (63597)	Operation Days: Operation Days Edgeline (63759)	Calendar Days: Operation Days/Calendar Days Centerline (63597)	Calendar Days: Operation Days/Calendar Days Edgeline (63759)	Week Days: Operation Days/Week Days Centerline (63597)	Week Days: Operation Days/Week Days Edgeline (63759)
	Number of Days							
April	30	21	0	0	0%	0%	0%	0%
May	31	23	13	10	42%	32%	57%	43%
Jun	30	21	16	5	53%	17%	76%	24%
July	31	22	14	15	45%	48%	64%	68%
August	31	23	15	6	48%	19%	65%	26%
September	30	20	12	3	40%	10%	60%	15%
October	31	23	8	1	26%	3%	35%	4%
November	30	22	2	4	7%	13%	9%	18%
Total	244	175	80	44	33%	18%	46%	25%

TABLE 5.11
Supporting Trucks Utilization Analysis (Crawfordsville): 2012 Operation, Calendar & Week Days

Striping Operation Month in 2012	Calendar Days	Week Days	Operation Days: Dump Truck 61133	Operation Days: Dump Truck 61288	Operation Days: Bed Truck 61118	Operation Days: Pickup Truck 61459	Calendar Days: Op. Days/ Cal. Days 61133	Calendar Days: Op. Days/ Cal. Days 61288	Calendar Days: Op. Days/ Cal. Days 61118	Calendar Days: Op. Days/ Cal. Days 61459	Week Days: Op. Days/ Cal. Days 61133	Week Days: Op. Days/ Cal. Days 61288	Week Days: Op. Days/ Cal. Days 61118	Week Days: Op. Days/ Cal. Days 61459
	Number of Days													
April	30	21	11	3	8	15	37%	10%	27%	50%	52%	14%	38%	71%
May	31	23	15	4	9	16	48%	13%	29%	52%	65%	17%	39%	70%
Jun	30	21	13	17	12	12	43%	57%	40%	40%	62%	81%	57%	57%
July	31	22	15	10	12	15	48%	32%	39%	48%	68%	45%	55%	68%
Aug.	31	23	3	16	11	17	10%	52%	35%	55%	13%	70%	48%	74%
Sept.	30	20	0	10	9	13	0%	33%	30%	43%	0%	50%	45%	65%
Oct.	31	23	0	6	6	18	0%	19%	19%	58%	0%	26%	26%	78%
Nov.	30	22	0	4	7	11	0%	13%	23%	37%	0%	18%	32%	50%
Total	244	175	57	70	74	117	23%	29%	30%	48%	33%	40%	42%	67%

NOTE: Op. = operation; Cal. = calendar.

TABLE 5.12
Supporting Trucks Utilization Analysis (Greenfield): Operation, Calendar & Week Days

Striping Operation Month in 2012	Calendar Days	Week Days	Operation Days: Dump Truck 63854	Operation Days: Dump Truck 63713	Operation Days: Bed Truck 63749	Calendar Days: Operation Days/Calendar Days (63854)	Calendar Days: Operation Days/Calendar Days (63713)	Calendar Days: Operation Days/Calendar Days (63749)	Week Days: Operation Days/Week Days (63854)	Week Days: Operation Days/Week Days (63713)	Week Days: Operation Days/Week Days (63749)
	Number of Days										
April	30	21	3	14	14	10%	47%	47%	14%	67%	67%
May	31	23	12	8	14	39%	26%	45%	52%	35%	61%
Jun	30	21	9	13	16	30%	43%	53%	43%	62%	76%
July	31	22	16	8	14	52%	26%	45%	73%	36%	64%
August	31	23	8	14	19	26%	45%	61%	35%	61%	83%
September	30	20	14	12	17	47%	40%	57%	70%	60%	85%
October	31	23	6	14	18	19%	45%	58%	26%	61%	78%
November	30	22	6	15	17	20%	50%	57%	27%	68%	77%
Total	244	175	74	98	129	30%	40%	53%	42%	56%	74%

(Monday–Friday). Tables 5.9 through 5.16 present a summary of utilization analysis. The following assumptions were made for the analysis:

- One operation day is counted if any movement of a striping truck occurs regardless of productivity.
- Weather effects are not considered.
- Differences such as work schedule, workload, and truck model in between districts are not considered.
- Week days are defined as five typical business days in a week, from Monday to Friday.

The number of operation days can be conveniently counted from "Striping Report +" located under "Reports" main tab → "*Off Road*" *sub tab* → "Specialty" tab. Data for supporting truck utilization analysis is retrieved from "Travel Report +". Supporting truck operation days can be retrieved from this report only by manually counting days because there is no summary report for supporting truck operation days. The Travel Report + is located under the "Reports" main tab → "On Road" sub tab → "Vehicle Usage" tab.

Monthly utilization ratios for striping trucks are presented in Tables 5.9 and 5.10. Crawfordsville's centerline truck was utilized at approximately 27 percent based on total calendar days and 38 percent based on total week days. Greenfield's centerliner was utilized at approximately 33 percent based on total calendar days and 46 percent based on total work days. Overall utilization in Greenfield could significantly increase if the striping season began in May because Greenfield did not perform any striping during the entire month of April 2012. The Greenfield centerline truck was utilized at 76 percent, which is the highest operation percentage among all monthly utilization analysis results. Average utilization ratios in the Greenfield district were 6–8 percent higher than Crawfordsville. Average monthly utilization for the centerline truck in the Greenfield district represents approximately 2.5 utilization days per normal business week. Edgeline trucks show much less utilization than centerline trucks. The significantly low utilization of the edgeline trucks indicates that new operation plans can improve overall utilization of the striping trucks over both districts.

Utilization ratios for the supporting vehicles are presented in Tables 5.11 and 5.12. The results revealed that both districts utilized supporting vehicles much more than striping trucks. However, these results did not indicate any relationship with actual productivity.

Utilization analysis merely indicates that there is a profound opportunity to improve overall usage of all striping trucks and supporting vehicles in both districts.

5.3 Idling Analysis

Idling in this study is defined as zero driving distance while the engine is running. Idle data is obtained as time unit from the website. Idling analysis provides a measurement of vehicle operation inefficiency in terms of unnecessary fuel consumption and excessive idling. Excessive idling produces more unnecessary global warming potential (GWP) gas, and requires more fuel and shorter maintenance schedule. Idling and driving time data can be retrieved from Travel Report + under the "Reports" main tab → "On Road" sub tab → "Vehicle Usage" sub-categories as shown in Figure 5.2.

Tables 5.13 through 5.16 present monthly idling data summaries from four striping trucks. The ratio of idle time to drive time in these tables indicates the magnitude of idling. A 100 percent in the column "Total Idle Time/Total Drive Time" indicates that there is an equal amount of cumulative idling and driving time in a month. Definitions for the various idling conditions are presented as follows:

- *Total Drive Time is the time period when striping truck moves greater than 0 mph.*
- *Total Idle Time is the time period when striping truck does not move and truck's engine is turned on.*
- *Total Parked Time is the time period when striping truck does not move and truck's engine is turned off.*
- *Total Time is the sum of Total Drive, Idle and Parked Time periods.*

In Table 5.15, the data for the Greenfield centerline striping truck (63597) indicates that idle time was greater than drive time in April 2012 because Greenfield district striping operations did not start during April 2012 and the first striping occurred in May 2012.

Idle time ratios for both centerline trucks and Crawfordsville edgeline truck are all in the 25–38 percent range. Greenfield edgeline truck shows an extremely low idle time ratio at approximately 9 percent mainly due to doubtable high total driving time in May and August as shown in Table 5.16. This indicates that there is a possibility of inaccurate data collection due to unknown reasons. Based on a trend shown in Total Idle Time/Total Drive Time ratios in three other striping trucks, it is plausibly assumed that the Greenfield edgeline striping truck Total Idle Time/Total Drive Time ratio is approximately 20–30 percent.

A total of four striping trucks in the Crawfordsville and Greenfield districts were manufactured by various manufacturers in different models and years. Table 5.17 shows a summary of model year and manufacturer.

As defined by the Environmental Protection Agency (EPA), "on-road" includes vehicles used on roads for transportation of passengers or freight; "off-road" includes vehicles, engines, and equipment used for construction, agriculture, recreation, and many other purposes (*27*). Within these two broad categories, on-road and off-road vehicles are further categorized by size, weight, use, and horsepower. Striping trucks can be classified as heavy-duty class-8 trucks that are greater than 33,000 pounds in gross vehicle weight (*28,29*). A class 8, 1995 model year heavy-duty diesel truck's miles per gallon (mpg) rate is 6.52 mpg (*30*). 6.52 mpg for the striping trucks was applied to estimate fuel costs regardless of vehicle type and model. For the purposes of this study, \$3.96 per gallon was applied as an average retail price of on-highway diesel fuel unit

TABLE 5.13
Crawfordsville Centerline Striping Truck (61457) Idle Time: 2012 Monthly Summary

Striping Operation Month in 2012	Total Drive Time (Min.)	Total Idle Time (Min.)	Total Idle Time/Total Drive Time (%)	Total Parked Time (Min.)	Total Time (Min.)
April	859	704	82	38,910	40,473
May	1,989	1,130	57	40,409	43,528
June	3,052	591	19	35,195	38,838
July	2,608	774	30	39,143	42,525
August	2,344	776	33	38,647	41,767
September	1,521	728	48	31,298	33,547
October	1,021	396	39	33,395	34,812
November	0	52	0	33,270	33,322
Total	13,394	5,151	38	290,267	308,812

TABLE 5.14
Crawfordsville Edgeline Striping Truck (61249) Idle Time: 2012 Monthly Summary

Striping Operation Month in 2012	Total Drive Time (Min.)	Total Idle Time (Min.)	Total Idle Time/Total Drive Time (%)	Total Parked Time (Min.)	Total Time (Min.)
April	627	247	39	29,712	30,586
May	1,627	400	25	29,923	31,950
June	1,531	422	28	32,576	34,529
July	1,515	568	37	40,385	42,468
August	2,230	654	29	38,792	41,676
September	706	192	27	28,165	29,063
October	398	94	24	37,334	37,826
November	160	68	43	40,424	40,652
Total	8,794	2,645	30	277,311	288,750

TABLE 5.15
Greenfield Centerline Striping Truck (63597) Idle Time: 2012 Monthly Summary

Striping Operation Month in 2012	Total Drive Time (Min.)	Total Idle Time (Min.)	Total Idle Time/Total Drive Time (%)	Total Parked Time (Min.)	Total Time (Min.)
April	26	79	304	24,648	24,753
May	3,146	600	19	39,812	43,558
June	3,478	762	22	30,731	34,971
July	3,898	942	24	37,356	42,196
August	4,428	1,047	24	29,431	34,906
September	3,236	648	20	31,248	35,132
October	1,006	567	56	38,752	40,325
November	621	320	52	24,293	25,234
Total	19,839	4,965	25	256,271	281,075

TABLE 5.16
Greenfield Edgeline Striping Truck (63759) Idle Time: 2012 Monthly Summary

Striping Operation Month in 2012	Total Drive Time (Min.)	Total Idle Time (Min.)	Total Idle Time/Total Drive Time (%)	Total Parked Time (Min.)	Total Time (Min.)
April	0	167	0	20,886	21,053
May	14,067	885	6	28,559	43,511
June	2,682	369	14	32,008	35,059
July	5,711	881	15	33,893	40,485
August	13,231	464	4	26,943	40,638
September	839	174	21	25,333	26,346
October	209	36	17	4,014	4,259
Nov 1–16	848	321	38	16,205	17,374
Total	37,587	3,297	9	187,841	228,725

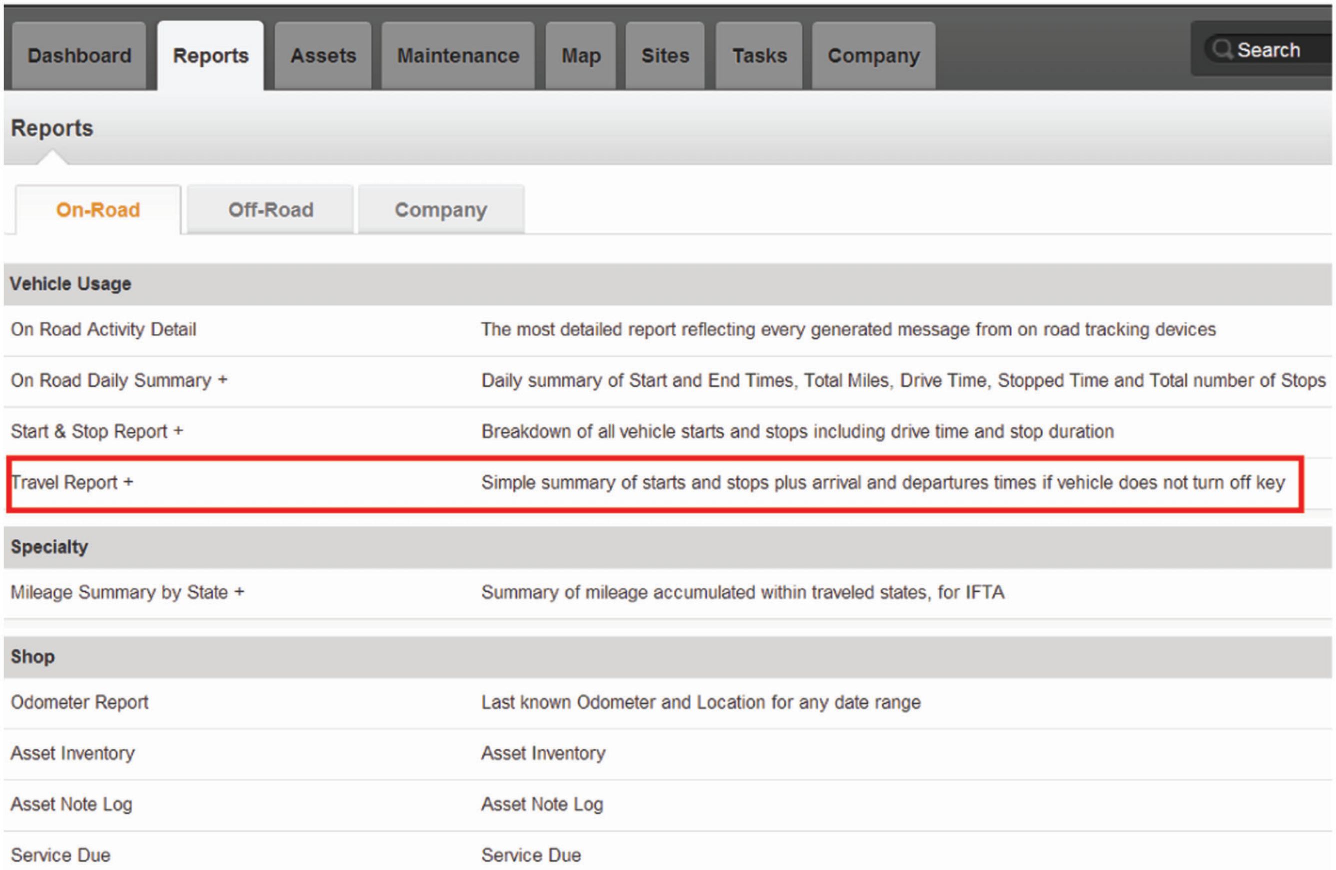

Figure 5.2 Travel report from the website.

price. Table 5.18 presents a summary of a striping truck's estimated fuel cost. Fuel consumption during idling status can also be estimated. Typical diesel trucks consume approximately one gallon per hour while idling (*31*). Using this rate, regardless of the type of vehicle, striping trucks idling fuel costs were estimated as shown in Table 5.19.

No specific references regarding additional vehicle maintenance cost due to excessive idling were found for this study. It is assumed that additional maintenance cost increases by the following factors: excessive idling hours, maintenance interval hours and average cost of preventive maintenance service. The following Equation 5.2 is based on these additional cost factors:

$$\text{Additional Vehicle Maintenance Cost} = \frac{\text{Excessive Idle Hours}}{\text{Maintenance Interval Hours}} \times (\text{maintenance cost}) \qquad \text{(Eq. 5.2)}$$

Additional maintenance costs were estimated by assuming the maintenance sequence every 300 hours of idling and $1,000 per maintenance. Table 5.20 presents a summary of additional maintenance costs based on the data collected between April 1 and November 30, 2012. Table 5.21 presents a summary of fuel consumption during operation and idling, and

TABLE 5.17
Striping Truck Information Summary Table

Asset Code, Location & Truck Type	Model Year	Manufacturer
61457 Crawfordsville Centerliner	2006	Sterling-Condor LCF
61249 Crawfordsville Edgeliner	2004	Autocar-WX
63597 Greenfield Centerliner	2005	Sterling-Condor LCF
63759 Greenfield Edgeliner	1995	GMC-WX Xpeditor

TABLE 5.18
Striping Truck Fuel Costs Estimation

Asset Code, Location & Truck Type	Total Drive Distance (Mileage Based on Odometer Reading in Tables 5.4 and 5.7)	Diesel Fuel Consumption	Fuel Cost
61457 Crawfordsville Centerliner	7,788 miles	7,788 miles/6.52 mpg = 1,194 gallons	$3.96 × 1,194 = $4,728
61249 Crawfordsville Edgeliner	5,690 miles	5,690 miles/6.52 mpg = 873 gallons	$3.96 × 873 = $3,457
63597 Greenfield Centerliner	9,355 miles	9,355 miles/6.52 mpg = 1,434 gallons	$3.96 × 1,434 = $5,679
63759 Greenfield Edgeliner	5,257 miles	5,257 miles/6.52 mpg = 806 gallons	$3.96 × 806 = $3,192

additional maintenance costs due to excessive idling from both Crawfordsville and Greenfield districts, but excluding regular maintenance costs. Idling fuel costs and additional maintenance costs can be trivial when compared to overall operation fuel costs. However, they can become significant when the costs of all striping vehicles throughout INDOT are cumulated.

5.4 Comparison Analysis Between the WMS and the Telematics Data

INDOT implements the Work Management System (WMS), provided by The Agile Assets® System, to manage enterprise asset management. This tool is typically aimed to effectively manage various resources including inventory, work scheduling, material usage, human resources (labor), and equipment. The WMS provides a work history tracking function for daily striping operations of each district and integrates all dispersed resource data throughout all districts. For the planning purpose, the WMS is able to generate work orders for the striping operation. The components of WMS work orders, including (1) Preventive maintenance (PM), (2) Plan, (3) Contract Plan, (4) Work Request, and (5) Day Cards, create a work order for an unplanned or emergency activity. The WMS is a web server system through the INDOT server system that can be accessed through the following web link: https://wms.indot.in.gov/ams_in/Kernel/w_login.jsp.

A work order generated by the WMS becomes a baseline for field operation during any given day. However, a field crew uses a daily input form to record actual daily operation data at the end of the day. There is no standardized data process protocol for this purpose. Each district has developed its own daily field input form to manually transfer completed field operation data to the WMS. For example, a daily input form used in the Crawfordsville district includes the following data:

- Striped locations,
- Types of striping (solid or skipped line),
- Amount of paint (white or yellow in gallons and drums),
- Amount of beads,
- Number of crew working hours, and
- Actual distance of striping.

The WMS is not designed to provide actual striping operation process and data monitoring functions including real-time vehicle and painting location tracking. It is impossible to reconstruct how striping operations have been completed efficiently in the field from the WMS data. As shown in Figure 5.3, a work order summary report generated by the WMS shows a summary of daily resource usage and baseline data for job costing. Only striping distance data is shown above the labor table in the accomplishment column. The striping distance is manually and directly taken from a dial gauge attached at the striping spraying guns. Advantage of this striping distance data collection is that striping distance provides actual sprayed striping length including multiple striping distances typically occurring during centerline striping operations.

It needs to be addressed that human intervention occurs during the manual input of field operation into the WMS. Figure 5.4 shows an example of a potential reporting error in the WMS. The telematics device recorded striping activity on June 20, 2012. However the WMS does not have any input data on the day. This error could be caused by human intervention. Automated data collection using the telematics reduced human errors and prevented erroneous data input.

TABLE 5.19
Idling Fuel Cost Estimation for Striping Trucks

Asset Code, Location & Truck Type	Total Idle Time (Table 5.14, 5.15, 5.16, and 5.17)	Diesel Fuel Consumption due to Idling	Fuel Cost due to Idling
61457 Crawfordsville Centerliner	5,151 min = 85.85 hours	1 gallons/hour × 85.85 hours = 85.85 gallons	$3.96 × 85.85 = $340
61249 Crawfordsville Edgeliner	2,645 min = 44.08 hours	1 gallons/hour × 43.42 hours = 43.42 gallons	$3.96 × 43.42 = $172
63597 Greenfield Centerliner	4,965 min = 82.75 hours	1 gallons/hour × 80.28 hours = 80.28 gallons	$3.96 × 80.28 = $317
63759 Greenfield Edgeliner	3,297 min = 54.95 hours	1 gallons/hour × 48.77 hours = 48.77 gallons	$3.96 × 48.77 = $193

TABLE 5.20
Additional Maintenance Cost Estimation for Striping Trucks

Asset Code, Location & Truck Type	Total Idle Time	Additional Maintenance Cost
61457 Crawfordsville Centerliner	5,151 min = 85.85 hours	(85.85 hours/300 hours) × $1000 = $286
61249 Crawfordsville Edgeliner	2,645 min = 44.08 hours	(44.08 hours/300 hours) × $1000 = $147
63597 Greenfield Centerliner	4,965 min = 82.75 hours	(82.75 hours/300 hours) × $1000 = $276
63759 Greenfield Edgeliner	3,297 min = 54.95 hours	(54.95 hours/300 hours) × $1000 = $183

5.5 Paint and Bead Volume Analysis

The telematics sensors were not configured to collect the amount of painting material consumption data including paint and glass bead volumes during 2012 striping season. However, additional sensors can be installed to collect material quantity data. Currently a field crew reports the amount of painting and glass bead consumption when they input striping mileage into the Work Management System (WMS). Thus, the paint and bead volume analysis is based on the existing WMS data. Tables 5.22 through 5.25 present monthly data summaries and analyses including striping mileages, as well as the amount of paint and glass bead consumption.

As shown in Tables 5.22 through 5.25, there is a positive correlation between striping mileage and material consumption. Greenfield centerline truck (63597) has the highest striping mileage (2,020 miles), as well as the largest total paint volume (33,805 gallons) and glass bead consumption (227,650 pounds). Crawfordsville centerline truck (63597) has the second highest striping mileage (1,910 miles), as well as the second largest paint volumes (33,101 gallons) and glass bead consumption (197,050 pounds).

Tables 5.22 through 5.25 include the monthly paint volume and glass bead consumption rate during the 2012 striping season. The material consumption analysis results are summarized in terms of gallons per mile for paint, and pounds per mile and pounds per gallon for glass bead. Several findings are as follow:

- 61457 Crawfordsville centerline truck has the highest total paint consumption rate of 17.33 (White 1.91 + Yellow 15.42) gallons per mile.
- 63759 Greenfield edgeline truck has the lowest total paint consumption rate of 16.27 gallons per mile.
- 63597 Greenfield centerline truck has the highest glass bead consumption rate of 112.67 pounds per mile and 6.73 pounds per gallon.
- 61249 Crawfordsville edgeline truck has the lowest glass bead consumption rate of 100.32 pounds per mile and 5.95 pounds per gallon.
- 61249 Crawfordsville edgeline truck has the highest white paint consumption rate of 16.86 gallons per mile.
- 61457 Crawfordsville centerline truck has the highest yellow paint consumption rate of 15.42 gallons per mile.
- The difference between the trucks with the highest total paint consumption rate and the lowest total paint consumption rate is less than 7 percent (1.06 gallons per mile).
- The difference between the trucks with the highest glass bead consumption rate and the lowest glass bead consumption rate is less than 13 percent (12.35 pounds per mile)

Figures 5.5 through 5.8 are graphs plotting daily striping mileages from GT data and WMS. Cumulative painting volumes are expressed as a linear graph over the striping mileages. Data from the WMS and the telematics show almost identical mileages from the two edgeline trucks, but significant differences from the two centerline trucks due to the fact that the mileage measurement method between WMS and GT is different. The telematics data only records linear driving distance, regardless of the number of striping lines painted at a time, or for skipped lines. On the contrary, a WMS records actual cumulative striping distance from painter spray odometers, as in the case of multiple striping lines simultaneously painted.

5.6 Geospatial Operation Tracking and Striping Speed Analysis

The data for geospatial operation tracking analysis are retrieved from the "Map" main tab on the Website. Data filter options are located under the main tab. The filter options provide a selection of various parameters including: (1) Asset Type, (2) Date Range, (3) Speed Range and, (4) Reason Codes. Each reason code in the

TABLE 5.21
Summary of Cost Estimation for Striping Trucks

Asset Code, Location & Truck Type	Diesel Fuel Cost due to Drive Distance	Diesel Fuel Cost due to Idling	Additional Maintenance Cost	Total Cost
61457 Crawfordsville Centerliner	$4,728	$340	$286	$5,354
61249 Crawfordsville Edgeliner	$3,457	$172	$147	$3,776
63597 Greenfield Centerliner	$5,679	$317	$276	$6,272
63759 Greenfield Edgeliner	$3,192	$193	$183	$3,568
Total				**$18,970**

Indiana Department of Transportation
FY 2012
Multi-Lane Traffic (1091) -
CENTERLINE PAINT CREW

WORK ORDER SUMMARY

Page: 1 of 1
Date:06/26/2012
Time:5.30 PM

Management Unit:	(1091) - CENTERLINE PAINT CREW	Start Date:	06/25/2012
Work Order #:	8756784	End Date:	06/25/2012
Activity:	8300-ML - PAINT CENTERLINES		
Sub-Activity	00 - NO SUBACTIVITY		
Accomplishment:	74.62	Units:	PTM
Comments:			

Inv. Element	Route	Starting MP	Ending MP	Accomplishment
I0743210-ML	I 74	54.34	69.96	15.0
I0745410-ML	I 74	23.62	46.79	10.0
I0740610-ML	I 74	46.79	54.34	49.6

Labor:

Employee Name	Employee ID	Work Date	Wage Type	Hours	Total Cost
Sledge, William	10000013925	06/25/2012	REG	9.5	$ 198
Allgood, Burley	10000013952	06/25/2012	REG	9.5	$ 154
Plunkett, Andrew	10000273678	06/25/2012	REG	9.5	$ 109
Jones, Dennis	10000248502	06/25/2012	REG	9.5	$ 124
Riley, Brian	10000209885	06/25/2012	REG	9.5	$ 117
Bickel, Jeffrey	10000013953	06/25/2012	REG	9.5	$ 172

Equipment:

Comm No.	Equipment Name	Work Date	Total Hrs	Mileage	Total Cost
061457	CENTERLINER TRUCK	06/25/2012	9.5		$ 466
061133	SINGLE AXLE DUMP TRUCK	06/25/2012	9.5		$ 233
061288	SINGLE AXLE DUMP TRUCK	06/25/2012	9.5		$ 233
061460	STAKE TRUCK	06/25/2012	9.5		$ 167

Material:

Material Stock	Work Date	Amount	Unit	Total Cost
909M00140 - Pave Mark, Waterborne Paint, Wht	06/25/2012	288.9	GAL	$ 2,563
909M00150 - Pave Mark, Waterborne Paint, Ylw	06/25/2012	1095.9	GAL	$ 9,614
913M14130 - Glass Beads, Standard	06/25/2012	7000	LB	$ 1,980

Accomplishments:

Work Date	Accomplishment		TOTAL_COST
06/25/2012	74.62	PTM	0
Total Accomplishment:	*74.62*	*PTM*	*0*

LABOR TOTAL:	$ 875.01	MATERIAL TOTAL:	$ 14,156.39
EQUIPMENT TOTAL:	$ 1,097.25	OTHER COST:	$ 0.00
WORK ORDER TOTAL:	$ 16,128.64		

Figure 5.3 An example of daily work order summary.

INDOT WMS Work Orders							GT Striping Data	
WO #	Date	Amount	District	Management Unit	Activity		Week	Date
8700277	13-Jun-12	38.93 miles	1000 - Crawfordsville	1091 - Centerline Paint Crew	Paint Centerlines		24	6/13/2012
8700975	14-Jun-12	25.96 miles	1000 - Crawfordsville	1091 - Centerline Paint Crew	Paint Centerlines			6/14/2012
							25	6/20/2012
8755855	21-Jun-12		1000 - Crawfordsville	1091 - Centerline Paint Crew	Paint Centerlines		25	6/21/2012

Figure 5.4 An example of WMS reporting error.

TABLE 5.22
Paint and Glass Bead Consumption for Crawfordsville Centerline Truck (ID: 61457)

2012 Month	WMS Striping Mileages (Miles)	White Paint Volume (Gallons)	Yellow Paint Volume (Gallons)	Glass Bead Amount (Pounds)	White Paint Consumption Rate (gallons/mile)	Yellow Paint Consumption Rate (gallons/mile)	Glass Bead Consumption Rate	
							lbs/mile	lbs/gallon
April	165.58	0.00	2,742.66	16,300.00	0.00	16.56	98.44	5.94
May	360.30	21.58	5,867.40	37,150.00	0.06	16.28	103.11	6.31
June	424.11	1,147.57	6,516.39	40,200.00	2.71	15.36	94.79	5.25
July	394.18	583.15	6,018.18	39,650.00	1.48	15.27	100.59	6.01
August	221.26	1,037.90	3,085.38	26,750.00	4.69	13.94	120.90	6.49
September	244.37	379.85	3,776.64	25,600.00	1.55	15.45	104.76	6.16
October	100.25	470.80	1,453.66	11,400.00	4.70	14.50	113.72	5.92
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**1,910.05**	**3,640.85**	**29,460.31**	**197,050.00**	**1.91**	**15.42**	**103.16**	**5.95**

TABLE 5.23
Paint and Glass Bead Consumption for Crawfordsville Edgeline Truck (ID: 61249)

2012 Month	WMS Striping Mileages (Miles)	White Paint Volume (Gallons)	Yellow Paint Volume (Gallons)	Glass Bead Amount (Pounds)	White Paint Consumption Rate (Gallons/Mile)	Yellow Paint Consumption Rate (Gallons/Mile)	Glass Bead Consumption Rate	
							lbs/Mile	lbs/Gallon
April	116.18	1,951.26	0.00	11,500.00	16.80	0.00	98.98	5.89
May	267.60	4,514.68	0.00	27,050.00	16.87	0.00	101.08	5.99
June	353.60	5,981.87	0.00	34,645.00	16.92	0.00	97.98	5.79
July	271.15	4,562.48	0.00	27,400.00	16.83	0.00	101.05	6.01
August	285.01	4,820.74	0.00	28,700.00	16.91	0.00	100.70	5.95
September	95.65	1,587.78	0.00	9,550.00	16.60	0.00	99.84	6.01
October	28.42	487.81	0.00	3,350.00	17.16	0.00	117.87	6.87
November	10.27	172.08	0.00	1,050.00	16.76	0.00	102.24	6.10
Total	1,427.88	24,078.70	0.00	143,245.00	16.86	0.00	100.32	5.95

TABLE 5.24
Paint and Glass Bead Consumption for Greenfield Centerline Truck (ID: 63597)

2012 Month	WMS Striping Mileages (Miles)	White Paint Volume (Gallons)	Yellow Paint Volume (Gallons)	Glass Bead Amount (Pounds)	White Paint Consumption Rate (Gallons/Mile)	Yellow Paint Consumption Rate (Gallons/Mile)	Glass Bead Consumption Rate	
							lbs/Mile	lbs/Gallon
April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	515.62	1,335.15	7,003.35	54,950.00	2.59	13.58	106.57	6.59
June	527.47	589.06	8,370.05	59,300.00	1.12	15.87	112.42	6.62
July	284.80	565.45	4,175.15	37,000.00	1.99	14.66	129.92	7.80
August	393.75	2,216.65	4,522.75	46,450.00	5.63	11.49	117.97	6.89
September	182.30	1,325.48	1,756.17	18,100.00	7.27	9.63	99.29	5.87
October	61.34	402.05	632.00	6,900.00	6.55	10.30	112.49	6.67
November	55.21	153.73	758.40	4,950.00	2.78	13.74	89.66	5.43
Total	2,020.49	6,587.55	27,217.87	227,650.00	3.26	13.47	112.67	6.73

TABLE 5.25
Paint and Glass Bead Consumption for Greenfield Edgeline Truck (ID: 63759)

2012 Month	WMS Striping Mileages (Miles)	White Paint Volume (Gallons)	Yellow Paint Volume (Gallons)	Glass Bead Amount (Pounds)	White Paint Consumption Rate (Gallons/Mile)	Yellow Paint Consumption Rate (Gallons/Mile)	Glass Bead Consumption Rate	
							lbs/Mile	lbs/Gallon
April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	395.90	6,527.60	0.00	42,000.00	16.49	0.00	106.09	6.43
June	171.30	2,789.00	0.00	18,050.00	16.28	0.00	105.37	6.47
July	498.77	8,134.70	0.00	51,250.00	16.31	0.00	102.75	6.30
August	172.65	2,726.50	0.00	17,950.00	15.79	0.00	103.97	6.58
September	48.20	739.20	0.00	5,050.00	15.34	0.00	104.77	6.83
October	47.10	823.20	0.00	5,150.00	17.48	0.00	109.34	6.26
November	78.24	1,230.60	0.00	8,500.00	15.73	0.00	108.64	6.91
Total	1,412.16	22,970.80	0.00	147,950.00	16.27	0.00	104.77	6.44

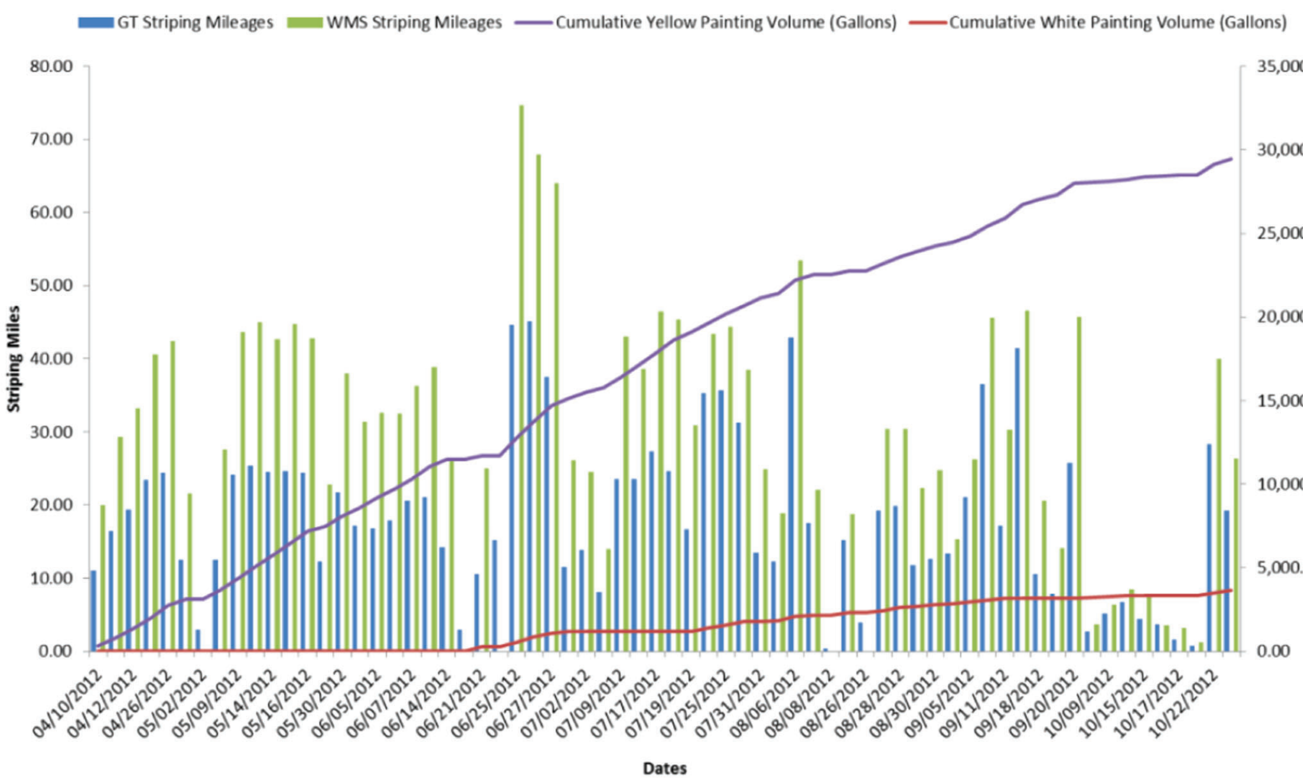

Figure 5.5 Striping mileages and cumulative paint volume for Crawfordsville centerline truck (ID: 61457).

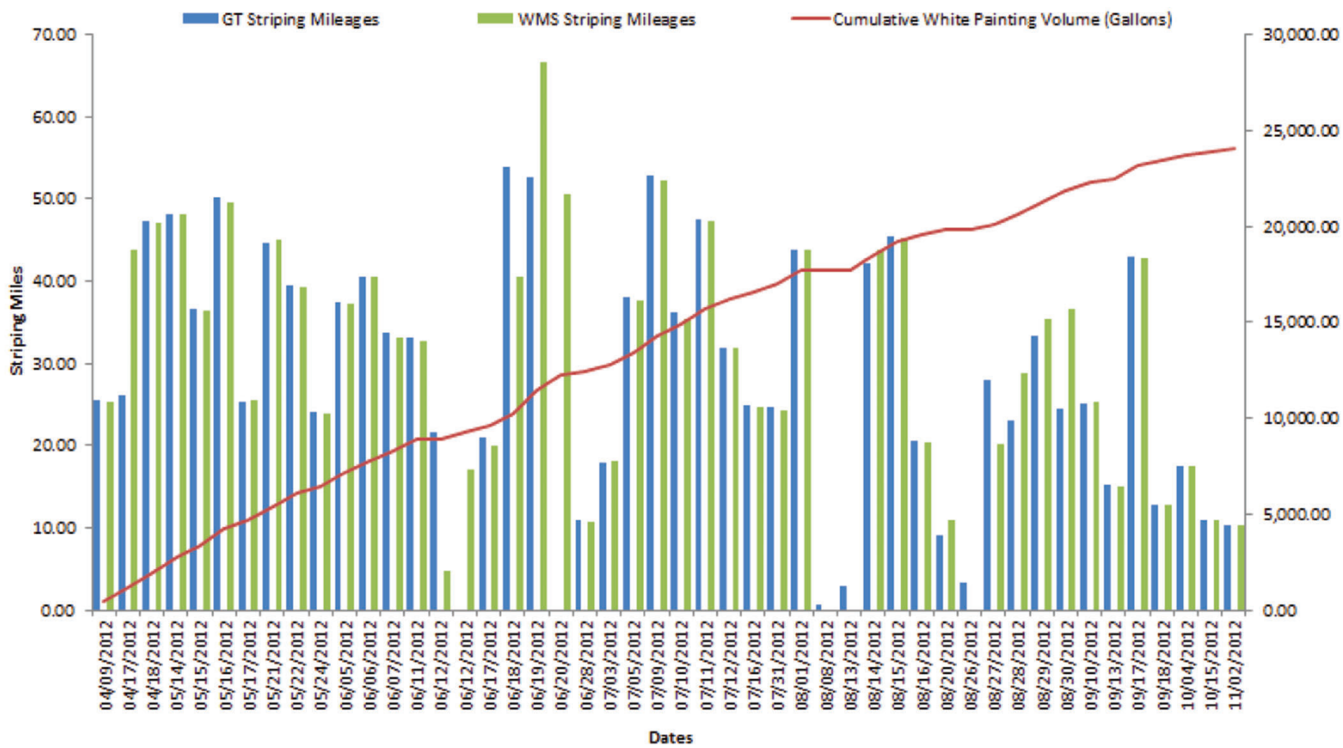

Figure 5.6 Striping mileages and cumulative paint volume for Crawfordsville edgeline truck (ID: 61249).

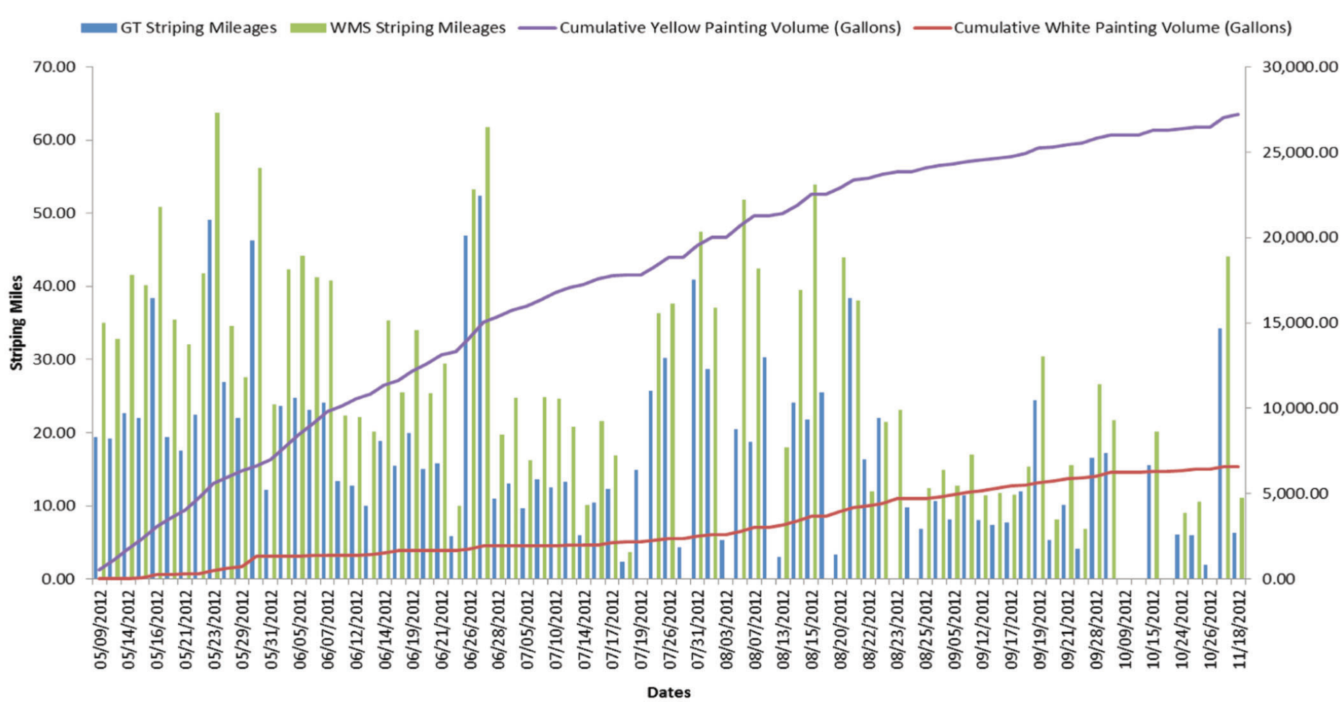

Figure 5.7 Striping mileages and cumulative paint volume for Greenfield centerline truck (ID: 63597).

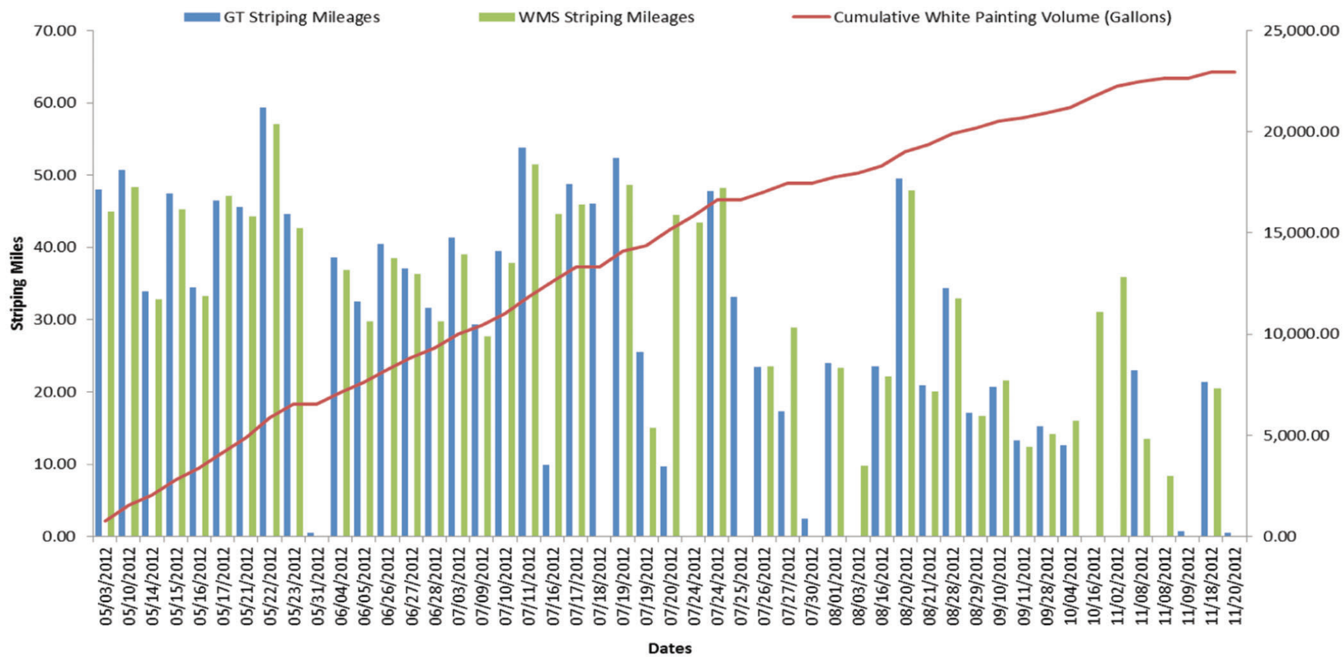

Figure 5.8 Striping mileages and cumulative paint volume for Greenfield edgeline truck (ID: 63759).

segments field shown in Figure 5.9 represents a specific set of data points. For example, when the Engine Started code is selected, all other data points are excluded. Users can develop a geospatial operation tracking map by retrospect asset movement on the map. Map segments were created and connected between filtered points from the filter options. All data for the segments should be determined by the user and segments should be continuously updated. Segment options are based on data signal properties, for example, AN3 selects "above threshold" and D3 selects "On."

Figure 5.9 is the screen view of filters and segment options used to obtain the map in Figure 5.10. Figure 5.10 shows an example of daily operation segments map taken from the website for Crawfordsville centerliner (61457) on June 13, 2012. Segments are generated by connecting data

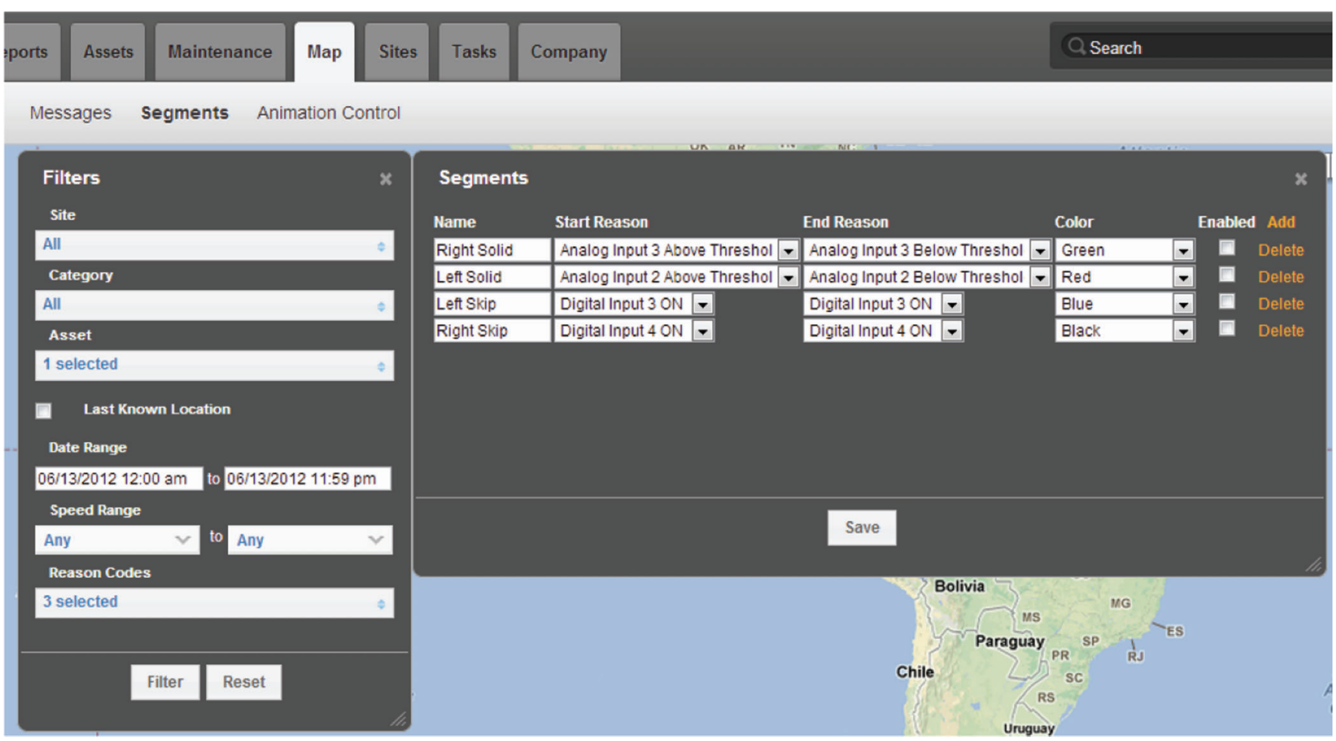

Figure 5.9 Gauge Smart Hub filter and segment query.

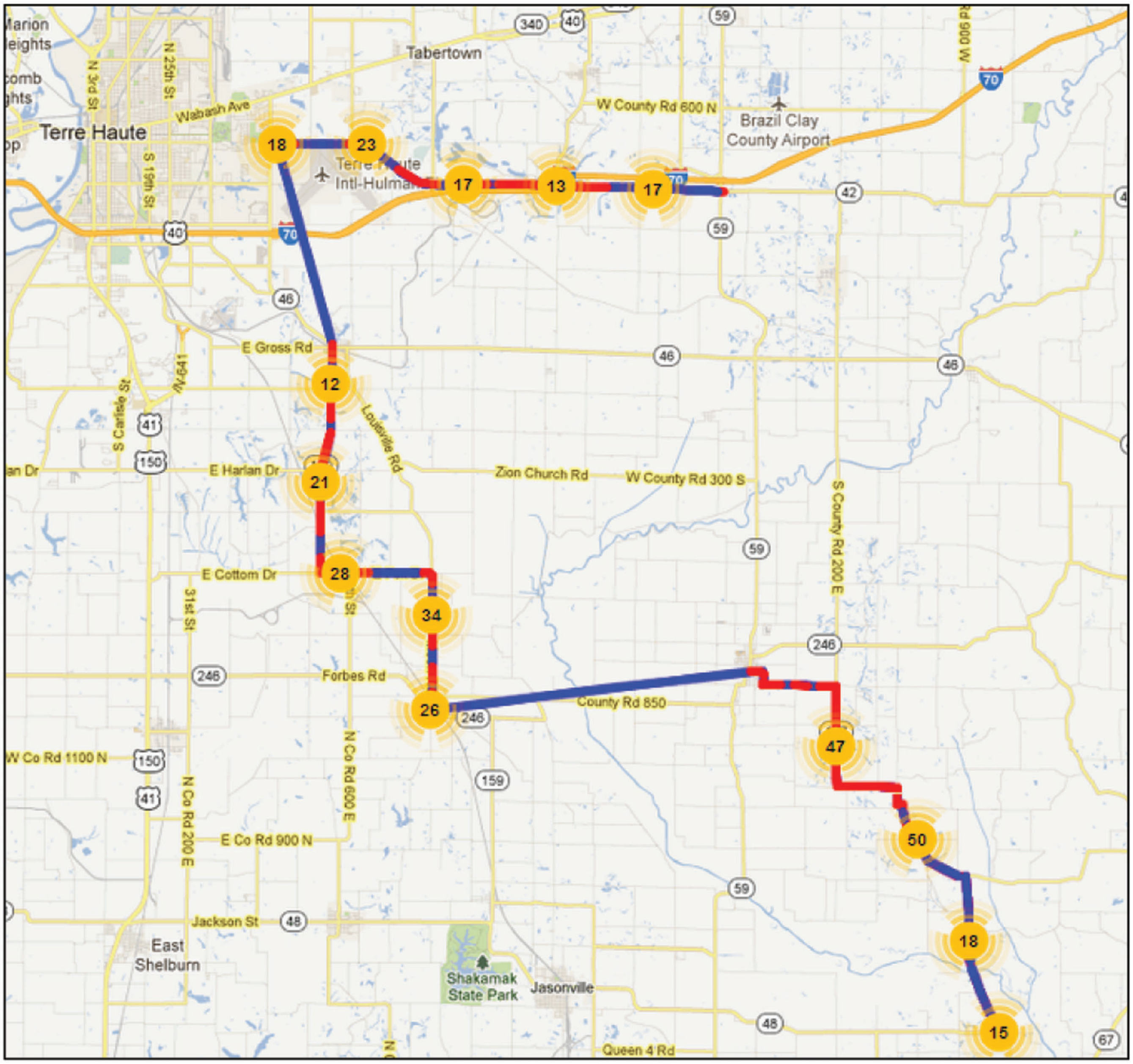

Figure 5.10 Crawfordsville centerline (61457) geospatial operation map on June 13, 2012.

points after filtering out unwanted data, and do not take speed into account. On the map (1) the blue line segments represent skip lines, (2) red line segments represent solid lines and (3) yellow dots with numbers represent data point locations.

Figures 5.11 and 5.12 are geospatial operation maps drawn using telematics data. Figure 5.11 shows the daily operation segments of a striping truck. Each segment is represented by a different color: (1) blue represents Start-to-Site, (2) green represents Site-to-Finish, (3) red represents Striping and (4) purple represents Non-Striping segments. Segment lengths and operation dates are also shown on the same slide. Figure 5.12 demonstrates monthly painting segments of a striping truck. Painting segments are manually drawn and each arrow represents weekly striping truck operation. Each arrow color symbolizes a different week: (1) Brown represents Week #1, (2) Purple represents Week #2, (3) Red represents Week #3, (4) Green represents Week #4 and (5) Dark Blue represents Week #5. The Website can generate tracking maps similar to Figures 5.11 and 5.12. However, graphic demonstrations of the website maps are not able to show monthly striping summaries and distances using different colors at this moment. A tracking summary map, such as the one shown in Figure 5.12, can improve effectiveness of striping operation planning and evaluation.

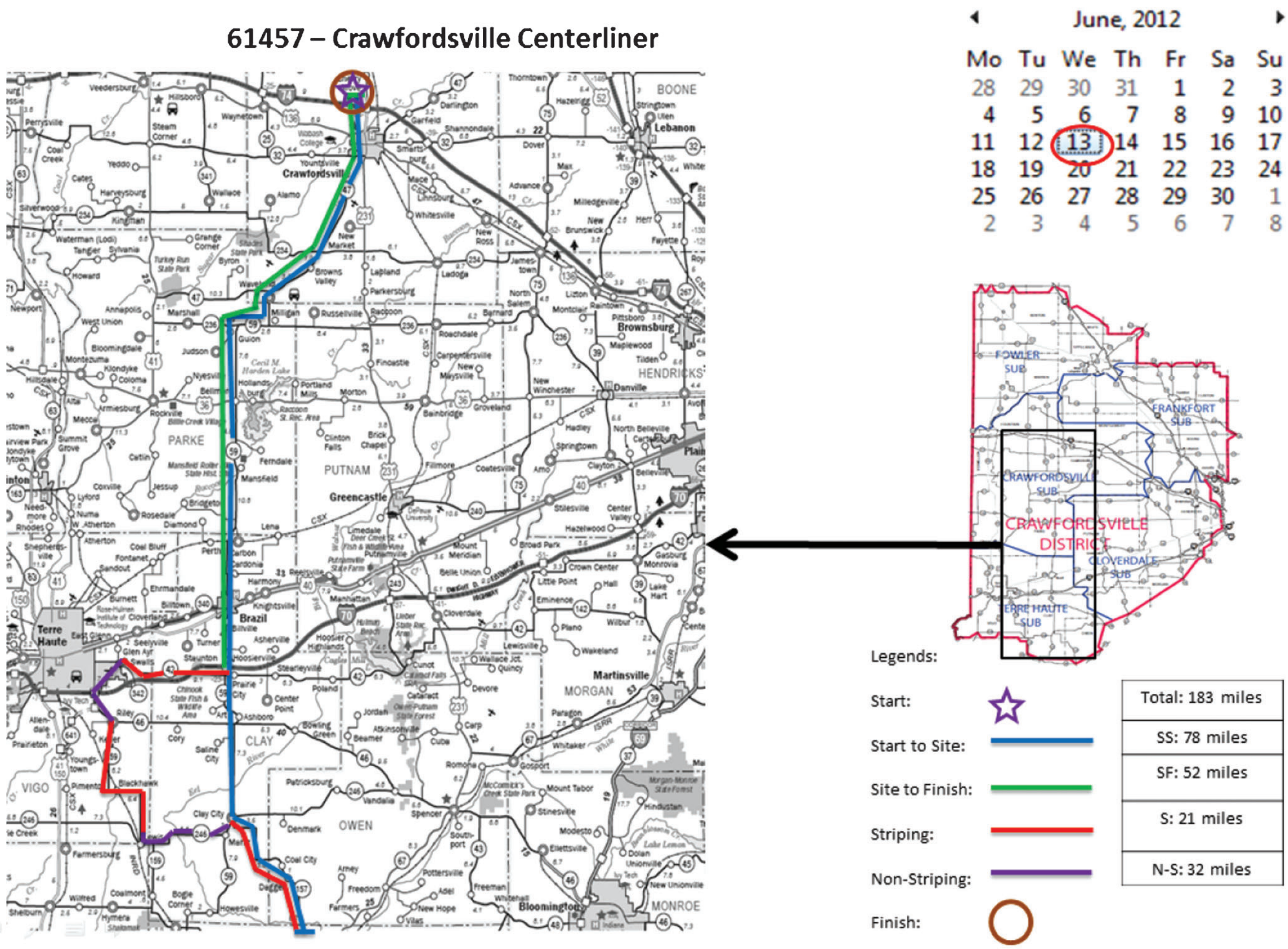

Figure 5.11 Crawfordsville centerline (61457) suggested daily geospatial operation Map on June 13, 2012.

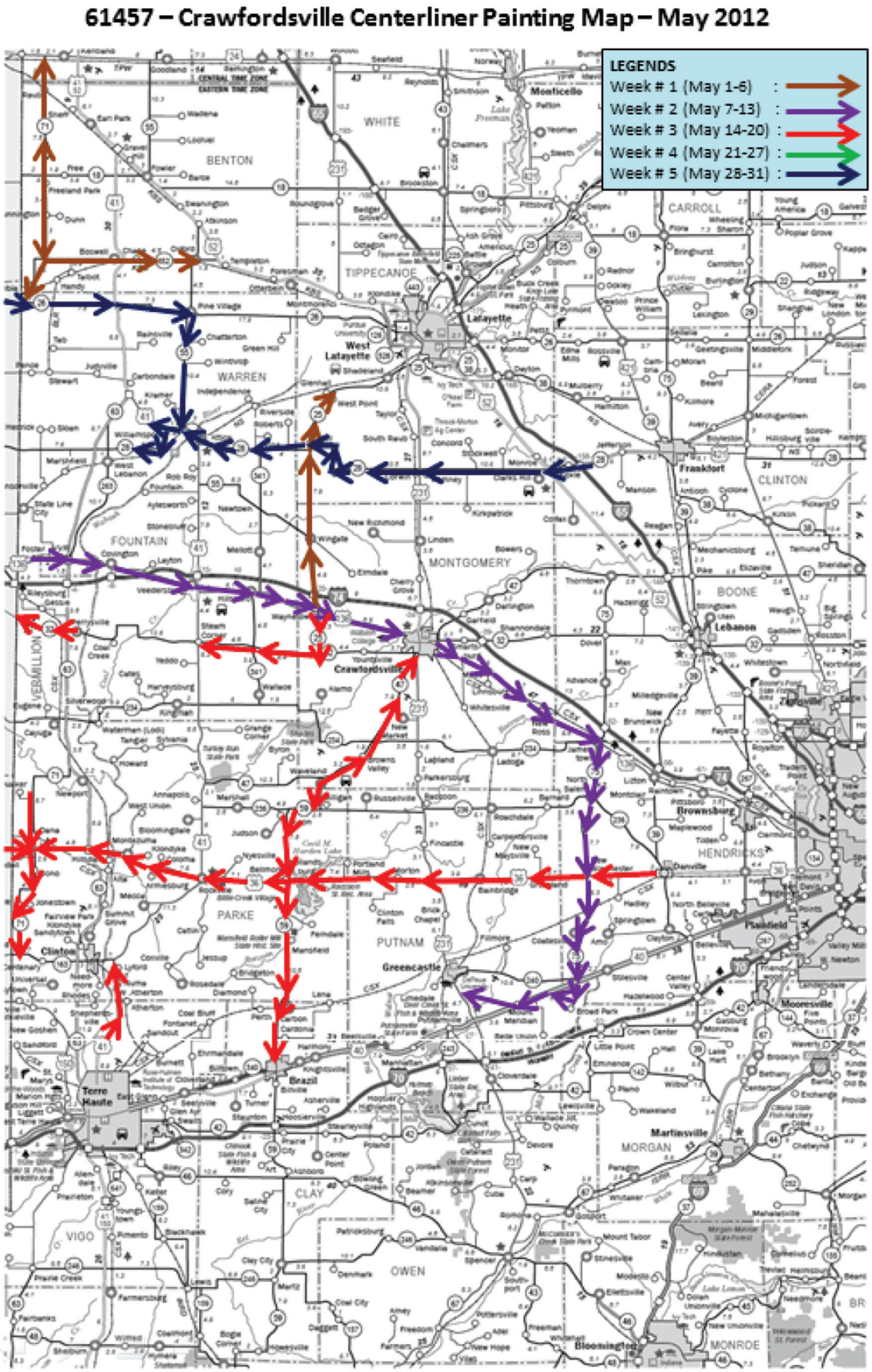

Figure 5.12 Crawfordsville centerline (61457) monthly geospatial operation map for May 2012.

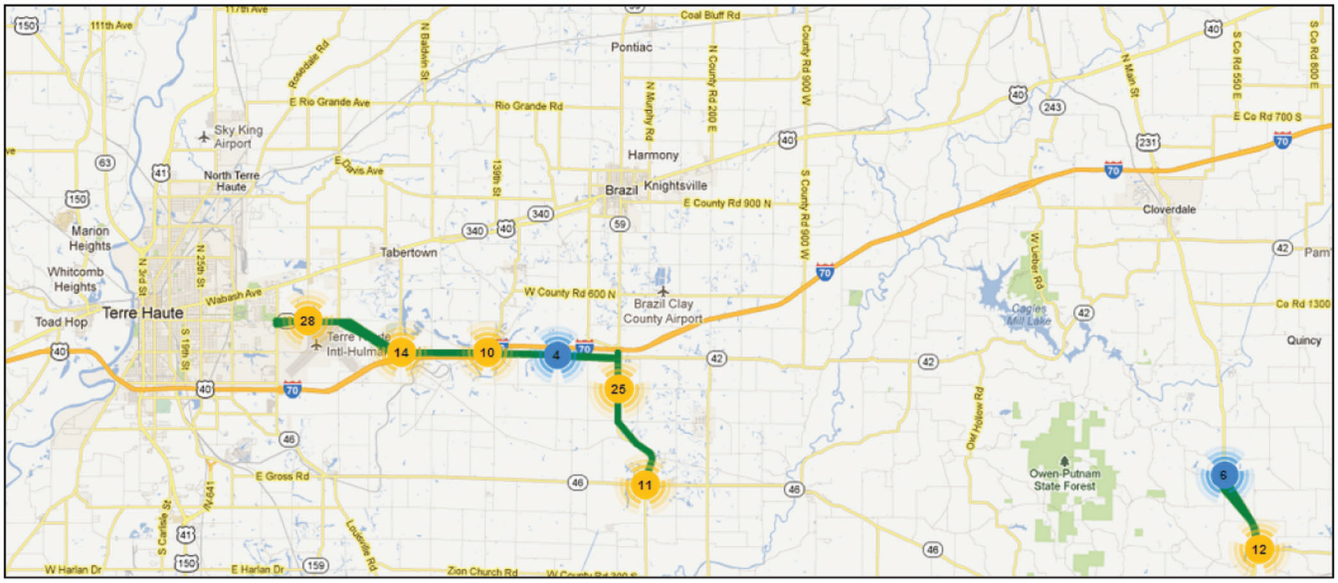

Figure 5.13 Crawfordsville edgeliner (61249) operation on June 11, 2012.

The website provides two ways of retrieving striping speed data. One is from the Off Road Activity Detail Report. This report shows all data input collected from field striping operations including striping truck speed. The website provides a function for retrieving striping speed by consulting the detailed map and filter options. Currently there are some limitations, for example: (1) no striping speed summary table to show average striping speed during a specific time period; and (2) Data Filters under the Map tab exclude all data points in between filtered data points on a truck's route. As a result, the segments between filtered data points are only connecting the remaining unfiltered data points, causing misinterpretation of the actual striping route and striping segments. The main cause of these limitations is that striping speed analysis was developed after initial website database and device configuration was already completed. These limitations can be resolved by taking an alternative technical approach.

Figure 5.13 shows striping segments from the website during a one day operation of Crawfordsville edgeliner striping truck (61249) on June 11, 2012. Segments are generated by connecting data points as recorded. When the speed filter is applied, as shown in Figures 5.14 (6–11 mph) and 5.15 (12–16 mph), only filtered data points are included, without representation of striping speed transition patterns. Therefore, it is almost impossible to reconstruct specific speed ranges on the map.

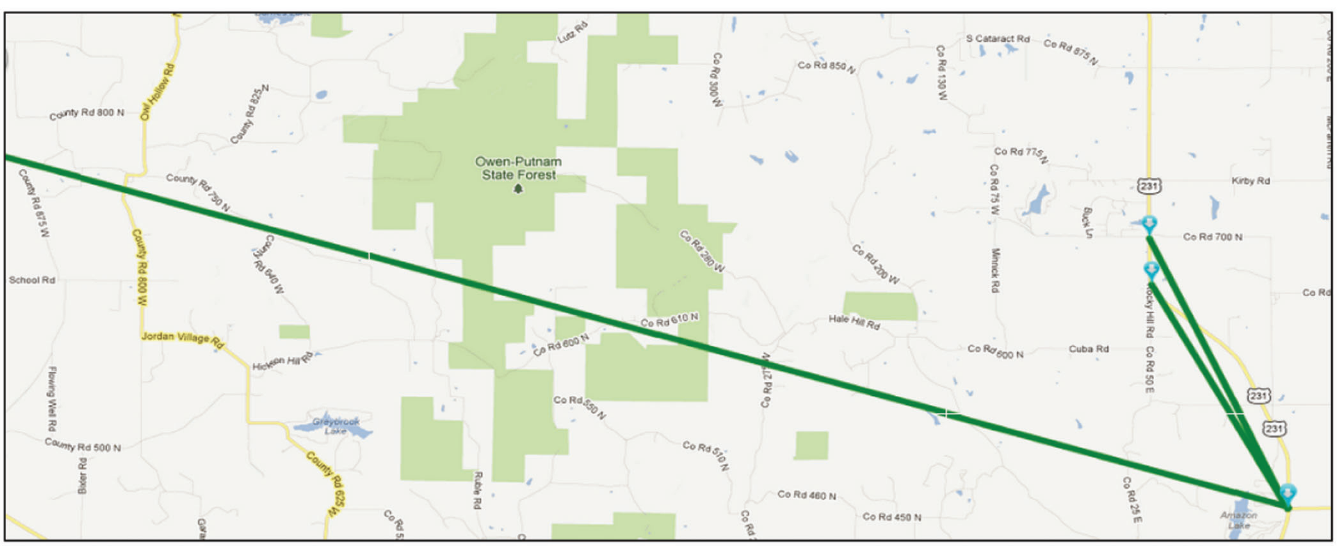

Figure 5.14 Crawfordsville edgeliner (61249) operation segment speed filter (6–11 mph) on June 11, 2012.

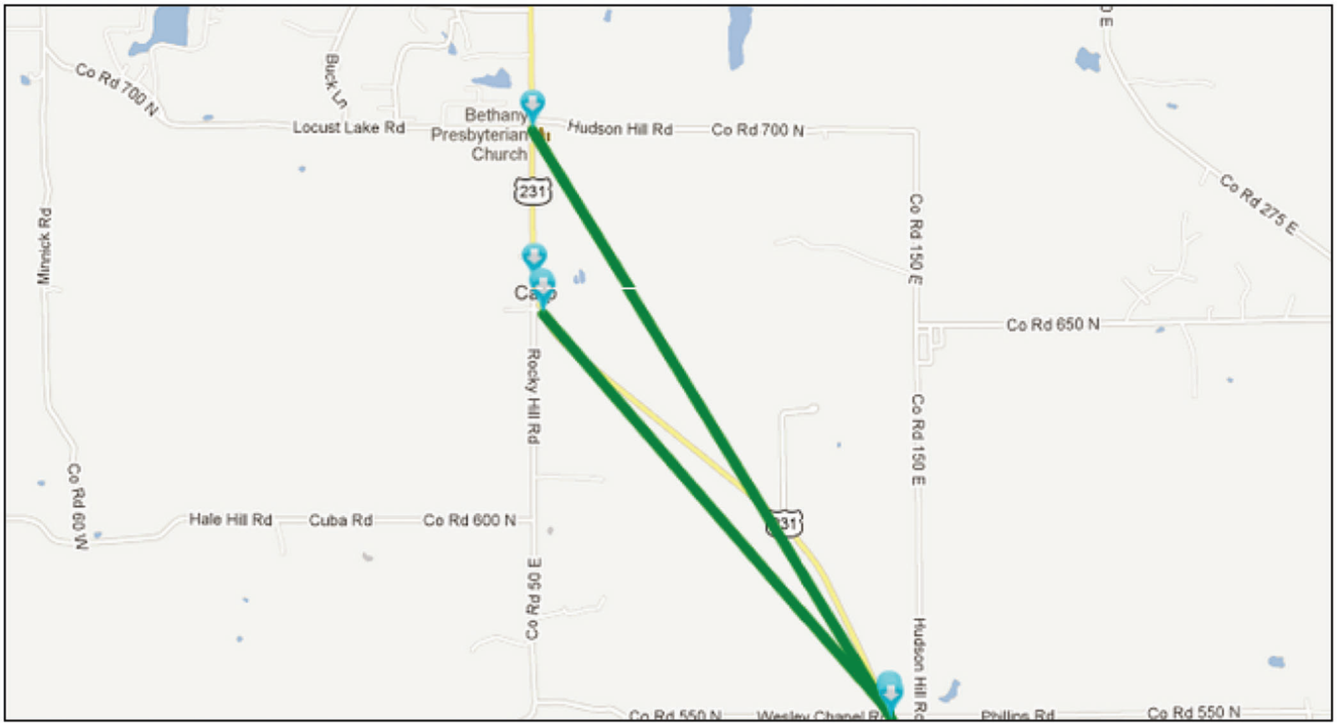

Figure 5.15 Crawfordsville edgeliner (61249) operation segment speed filter (12–16 mph) on June 11, 2012.

6. COMPARATIVE ANALYSIS AND METRICS

6.1 Existing Operation Boundary Analysis

An operation boundary is determined by driving ranges and locations of a striping trucks operation. As stated previously, a striping truck's daily operation is divided into five segmental distances: (1) Total Distance, (2) Striping Distance, (3) Start-to-Site Distance, (4) Site-to-Finish Distance and (5) Non-Striping Distance. These segments are created to summarize and understand the daily striping operation of each truck. Tables 6.1 and 6.2 summarize centerline and edgeline striping trucks' productivity data. Table 6.3 summarizes striping trucks' productive and nonproductive travel distance analysis in terms of distances (miles) and percentages (%). The sum of the three segments, Start-to-Site, Site-to-Finish and Non-Striping distances, is defined as nonproductive traveling distance and the term "Striping Distance" is only defined as productive traveling distance.

The results in Table 6.3 show that approximately 85 percent of total driving effort of centerline trucks and 75 percent of total driving effort of edgeline trucks were measured to be nonproductive distances, combining (1) Start-to-Site, (2) Site-to-Finish and (3) Non-Striping distances. It concludes that the existing district operation boundary does not provide fully effective boundary condition for the striping operations. Joint operation boundary conditions combining Crawfordsville and Greenfield districts will generate more nonproductive travel distances due to more scattered geographical locations of striping sites over the two combined districts. It is assumed that maximum daily traveling distance is constant and smaller operation boundaries will increase striping distance within a given day. Total productive distance (striping distance) can be increased if nonproductive distance decreases. Therefore, an alternative sub-district operation boundary scenario was developed and examined to assess the impact of operation boundary locations in relation to driving distance from the center of deployment.

The existing striping operation is assumed to use a centralized truck deployment operation plan in both

TABLE 6.1
2012 Centerline Striping Trucks Distance Data

	Crawfordsville Centerline (61457)		Greenfield Centerline (63597)	
Travel Segments	**Mileages (Miles)**	**Mileages/Total Mileages (%)**	**Mileages (Miles)**	**Mileages/Total Mileages (%)**
Striping Distance	1,211	15.5%	1,368	14.6%
Start-to-Site	2,363	30.3%	2,211	23.6%
Site-to-Finish	2,342	30.1%	2,371	25.3%
Non-Striping	1,872	24.0%	3,405	36.4%
Total Mileage	7,788	100.0%	9,355	100.0%

TABLE 6.2
2012 Edgeline Striping Trucks Distance Data

Travel Segments	Crawfordsville Edgeline (61249)		Greenfield Edgeline (63759)	
	Mileages (Miles)	Mileages/Total Mileages (%)	Mileages (Miles)	Mileages/Total Mileages (%)
Striping Distance	1,357	23.8%	1,348	25.6%
Start-to-Site	1,706	30.0%	975	18.5%
Site-to-Finish	1,518	26.7%	1,073	20.4%
Non-Striping	1,110	19.5%	1,860	35.4%
Total Mileage	5,690	100.0%	5,257	100.0%

Crawfordsville and Greenfield districts. Striping trucks depart from a single designated location and return back to the same location at the end of each operation day or striping trip. It is not plausible to minimize nonproductive distances without significant operational plan updates. Operation boundary analysis based on sub-districts in a district boundary was performed to confirm a need of alternative operational boundary development.

There are a total of five sub-districts in each district. The main concept of utilizing the sub-district boundaries is to divide a large district into five smaller ones in order to complete striping work in one sub-district before moving on to the next sub-district. The existing sub-district boundary becomes an operational boundary for striping trucks. This concept focuses on minimizing nonproductive driving distances. The names of the five sub-districts in each district are as follows:

- Crawfordsville District: Fowler, Frankfort, Crawfordsville, Cloverdale, and Terre Haute
- Greenfield District: Tipton, Albany, Indianapolis, Greenfield, and Cambridge

Some assumptions should be made for this analysis. Striping crews and trucks shall be a mobile team and follow sub-district operation plans. Striping trucks may be assigned daily to various striping locations within a sub-district until all striping jobs in a sub-district are completed. The arrows in Figure 6.1 represent an example of the work flow pattern between sub-districts.

Table 6.4 presents the number of operation days and roadway distances between Indianapolis and the geographical center of each sub-district. The number of operation days implies the striping work amount in each sub-district and distribution of the striping work.

Because a striping truck can work in multiple sub-districts in one day, existing 2012 striping geospatial location data have been further analyzed to identify distances within a sub-district. Tables 6.5 through 6.8 each consist of two tables. The top table presents the number of operation days, sorted by the districts visited each day, and the bottom table estimates the number of operation days associated with each specific sub-district. Operation days and distances in the top table are equally divided by the number of sub-districts. For example, the number of operation days in the second row and the first column of Table 6.5 is two, which is then equally divided between the two sub-districts. Each sub-district (Cloverdale and Terre Haute) gets one operation day, which is then summed up in the bottom table for each sub-district.

Tables 6.5 and 6.6 indicate that approximately 25 percent of total mileage from most sub-districts is made up of edgeline striping distance. Interestingly, the Indianapolis sub-district shows relatively smaller Start-to-site and Site-to-finish distances. However, extremely high non-striping distance hinders the chance of increasing striping distance. This means that an edgeline truck was assigned to sparsely dispersed striping locations in the Indianapolis sub-district area. Crawfordsville and Greenfield sub-districts can be considered as geographical centers of the edgeline striping operation, and thus provides the highest percentage of striping miles among all sub-districts.

Centerline striping operations show a much lower percentage of striping mileage compared to edgeline striping. Tables 6.7 and 6.8 indicate that only about 15

TABLE 6.3
2012 Productive and Nonproductive Travel Distance Analysis

Travel Distances	Centerline Trucks				Edgeline Trucks			
	Crawfordsville (61457)		Greenfield (63597)		Crawfordsville (61249)		Greenfield (63759)	
	Mileages (Miles)	Mileages/Total Mileages (%)	Mileages (Miles)	Mileages/Total Mileages (%)	Mileages (Miles)	Mileages/Total Mileages (%)	Mileages (Miles)	Mileages/Total Mileages (%)
Productive	1,211	15.5 %	1,368	14.6 %	1,357	23.8%	1,348	25.6 %
Nonproductive	6,577	84.5 %	7,987	85.4 %	4,333	76.2 %	3,909	74.4 %
Total Travel Mileage	7,788	100 %	9,355	100 %	5,690	100 %	5,257	100 %

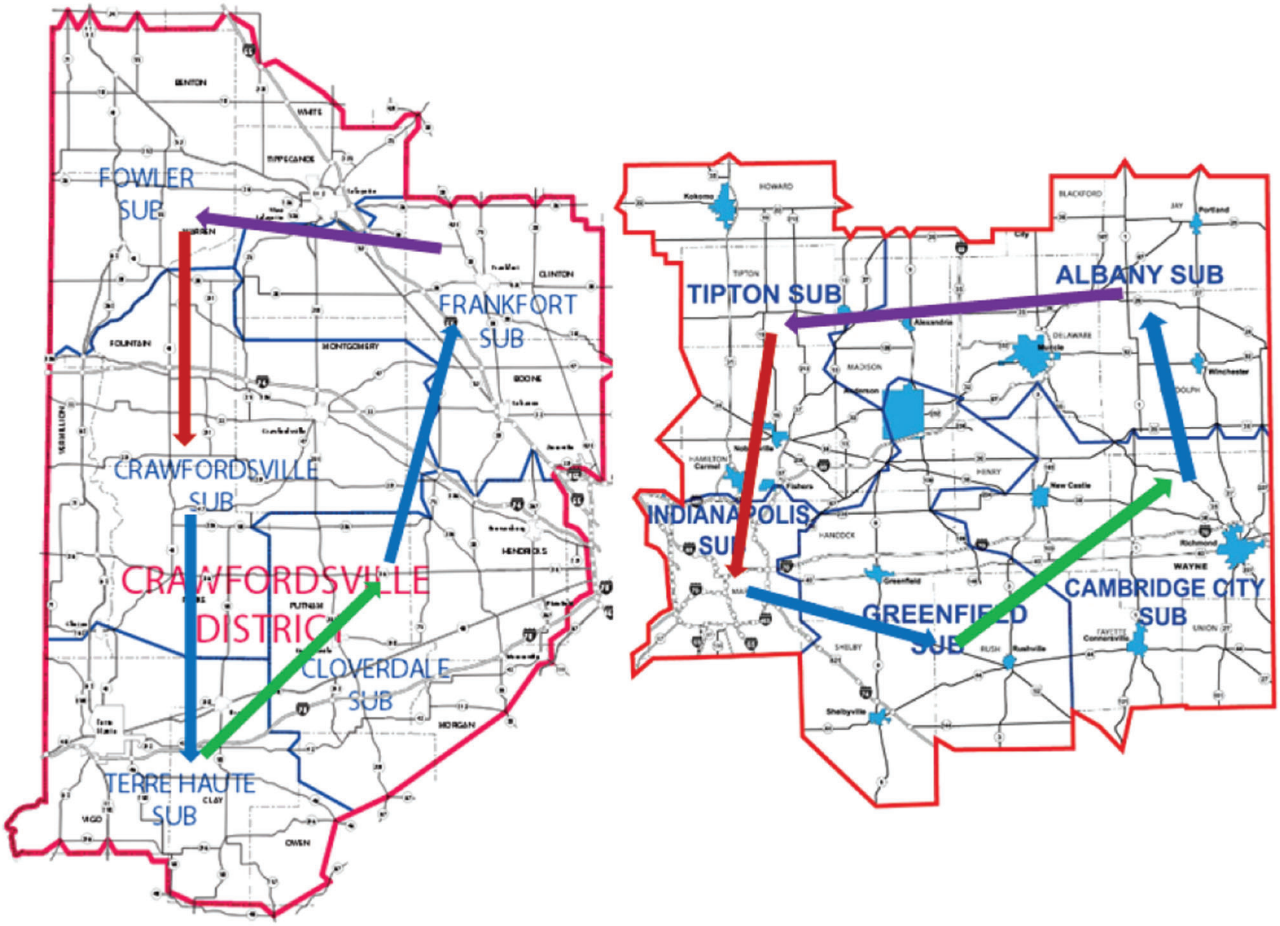

Figure 6.1 Decentralized striping truck operation conceptual pattern.

TABLE 6.4
Sub-district Average Distances Data

Districts	Sub-districts	Number of Operation Days (Days) (Obtained from Tables 6.6, 6.7, 6.8, and 6.9)	Distance from Indianapolis to Sub-districts (Miles)
Crawfordsville	Fowler	20.17	94.20
	Frankfort	17.50	46.30
	Crawfordsville	30.50	46.80
	Cloverdale	24.83	41.50
	Terre Haute	19.00	76.60
Greenfield	Tipton	20.33	40.90
	Albany	18.50	77.60
	Indianapolis	34.33	1.00
	Greenfield	31.33	25.00
	Cambridge City	19.50	59.90
Total		**236.00**	**509.80**

TABLE 6.5
2012 Crawfordsville Edgeline Truck (61249) Sub-district Data Summary

Number of Operation Days (Days)	Crawfordsville Sub-districts	Start To Site (Miles)	Striping (Miles)	Non-Striping (Miles)	Site To Finish (Miles)	Total (Miles)
7.00	Cloverdale	206	165	176	207	754
2.00	Cloverdale, Terre Haute	90	81	56	99	325
8.00	Crawfordsville	204	181	88	104	577
4.00	Crawfordsville, Cloverdale	55	127	219	21	422
1.00	Crawfordsville, Frankfort	45	10	82	31	169
3.00	Crawfordsville, Terre Haute	149	87	48	206	491
8.00	Fowler	401	251	85	341	1,077
1.00	Fowler, Cloverdale	8	23	137	0	167
2.00	Fowler, Frankfort	90	98	37	70	296
1.00	Fowler, Frankfort, Crawfordsville	2	33	93	19	147
3.00	Frankfort	106	68	16	98	288
1.00	Frankfort, Cloverdale	21	53	23	25	122
5.00	Terre Haute	329	179	50	296	855
46.00	All Sub-districts	1,706	1,357	1,110	1,518	5,690

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Crawfordsville Sub-districts	Number of Operation Days (Days)	Start To Site (Miles)	Striping (Miles)	Non-Striping (Miles)	Site To Finish (Miles)	Total (Miles)
Fowler	9.83	450 (33%)	322 (24%)	202 (15%)	382 (28%)	1,357
Frankfort	5.33	185 (29%)	159 (25%)	118 (19%)	168 (27%)	631
Crawfordsville	12.33	329 (28%)	**305 (26%)**	293 (25%)	240 (21%)	1,167
Cloverdale	11.00	292 (23%)	307 (24%)	393 (31%)	279 (22%)	1,272
Terre Haute	7.50	448 (36%)	263 (21%)	102 (8%)	449 (36%)	1,263
All Sub-districts	46.00	1,706	1,357	1,110	1,518	5,690

TABLE 6.6
2012 Greenfield Edgeline Truck (63759) Sub-district Data Summary

Number of Operation Days (Days)	Sub-districts: Greenfield	Start To Site (Miles)	Striping (Miles)	Non-striping (Miles)	Site to Finish (Miles)	Total (Miles)
3.00	Albany	189	120	59	213	582
1.00	Albany, Cambridge City	31	45	51	29	156
2.00	Albany, Greenfield	56	79	43	61	239
3.00	Cambridge City	88	104	130	121	442
9.00	Greenfield	169	199	332	203	903
3.00	Greenfield, Cambridge City	11	161	95	69	336
9.00	Indianapolis	128	192	500	95	914
2.00	Indianapolis, Greenfield	25	78	49	19	171
5.00	Tipton	170	139	132	155	595
1.00	Tipton, Albany	38	34	45	35	152
2.00	Tipton, Greenfield	29	62	143	27	261
2.00	Tipton, Greenfield, Albany	39	55	113	39	246
1.00	Tipton, Greenfield, Indianapolis	1	48	74	7	129
1.00	Tipton, Indianapolis	0	33	95	2	131
44.00	All Sub-districts	975	1,348	1,860	1,073	5,257

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Sub-districts: Greenfield	Number of Operation Days (Days)	Start To Site (Miles)	Striping (Miles)	Non-striping (Miles)	Site to Finish (Miles)	Total (Miles)
Tipton	8.00	217 (22%)	238 (24%)	336 (34%)	201 (20%)	991
Albany	5.67	265 (28%)	218 (23%)	166 (18%)	289 (31%)	937
Indianapolis	10.83	141 (13%)	263 (24%)	597 (54%)	107 (10%)	1,108
Greenfield	14.50	243 (16%)	423 (28%)	559 (36%)	306 (20%)	1,532
Cambridge City	5.00	109 (16%)	207 (30%)	203 (29%)	170 (25%)	689
All Sub-districts	44.00	975	1,348	1,860	1,073	5,257

TABLE 6.7
2012 Crawfordsville Centerline Truck (61457) Sub-district Data Summary

Number of Operation Days	Sub-districts: Crawfordsville	Start To Site (Miles)	Striping (Miles)	Non-Striping (Miles)	Site To Finish (Miles)	Total (Miles)
8.00	Cloverdale	329	103	81	288	800
4.00	Cloverdale, Terre Haute	166	87	187	171	611
10.00	Crawfordsville	236	186	175	213	810
5.00	Crawfordsville, Cloverdale	92	132	194	126	544
5.00	Crawfordsville, Frankfort	105	84	87	109	386
1.00	Crawfordsville, Frankfort, Cloverdale	13	24	41	63	141
3.00	Crawfordsville, Terre Haute	177	77	94	142	490
8.00	Fowler	466	129	131	441	1,166
1.00	Fowler, Cloverdale	3	19	99	0	122
2.00	Fowler, Crawfordsville	56	51	144	49	299
1.00	Fowler, Frankfort	4	45	129	2	181
1.00	Fowler, Frankfort, Crawfordsville	16	38	53	0	107
8.00	Frankfort	258	138	209	291	896
1.00	Frankfort, Cloverdale	29	13	50	34	126
8.00	Terre Haute	415	86	196	414	1,111
66.00	All Sub-districts	2,363	1,211	1,872	2,342	7,788

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Sub-districts: Crawfordsville	Number of Operation Days	Start To Site (Miles)	Striping (Miles)	Non-Striping (Miles)	Site To Finish (Miles)	Total (Miles)
Fowler	10.33	502 (33%)	199 (13%)	335 (22%)	467 (31%)	1,502
Frankfort	12.17	336 (25%)	229 (17%)	374 (28%)	385 (29%)	1,324
Crawfordsville	18.17	460 (26%)	378 (22%)	466 (27%)	447 (26%)	1,751
Cloverdale	13.83	478 (31%)	236 (15%)	360 (23%)	474 (31%)	1,548
Terre Haute	11.50	586 (35%)	168 (10%)	337 (20%)	570 (34%)	1,662
All Sub-districts	66.00	2,363	1,211	1,872	2,342	7,788

TABLE 6.8
2012 Greenfield Centerline Truck (63597) Sub-district Data Summary

Number of Operation Days (Days)	Sub-districts: Greenfield	Start To Site (Miles)	Striping (Miles)	Non-striping (Miles)	Site to Finish (Miles)	Total (Miles)
9.00	Albany	292	166	321	353	1,132
3.00	Albany, Cambridge City	46	53	136	123	358
2.00	Albany, Greenfield	66	35	61	70	233
9.00	Cambridge City	270	160	213	267	910
10.00	Greenfield	217	193	188	250	847
8.00	Greenfield, Cambridge City	169	185	415	164	933
22.00	Indianapolis	440	306	1,473	506	2,726
2.00	Indianapolis, Greenfield	87	14	134	19	254
10.00	Tipton	453	142	258	432	1,285
2.00	Tipton, Albany	77	58	61	107	303
1.00	Tipton, Greenfield	23	22	54	22	120
1.00	Tipton, Greenfield, Albany	30	30	43	42	145
1.00	Tipton, Indianapolis	38	4	50	17	109
80.00	All Sub-districts	2,211	1,368	3,405	2,371	9,355

↓

Sub-districts: Crawfordsville	Number of Operation Days	Start To Site (Miles)	Striping (Miles)	Non-Striping (Miles)	Site To Finish (Miles)	Total (Miles)
Tipton	12.33	533 (33%)	194 (12%)	355 (22%)	519 (32%)	1,600
Albany	12.83	397 (24%)	249 (15%)	464 (28%)	517 (32%)	1,627
Indianapolis	23.50	503 (17%)	315 (11%)	1,566 (54%)	524 (18%)	2,907
Greenfield	16.83	400 (24%)	**331 (20%)**	534 (32%)	401 (24%)	1,665
Cambridge City	14.50	378 (24%)	279 (18%)	488 (31%)	410 (26%)	1,555
All Sub-districts	80.00	2,211	1,368	3,405	2,371	9,355

percent of the total distance is actual striping distance. Crawfordsville and Greenfield sub-districts showed the highest striping distances. It revealed that geographical location significantly affected centerline striping productivity.

Regardless of field conditions and productivity factors, boundary locations significantly impact overall productivity, and using sub-district boundaries provides a chance for potential productivity improvement through alternative striping operation. There is no sub-district boundary simulation data, but it is expected that the most savings will be due to minimizing distances from Start-to-site and Site-to-finish within each sub-district. The time and mileage saved can instead be utilized for other productive work, such as increasing striping distance within the sub-district.

Several field conditions and productivity factors might need to be identified prior to an operation plan change. Examples include identifying the supply chain of painting materials to the sub-districts, operation and maintenance functions of the sub-districts including supporting vehicles, and accommodation of crew schedules and deployment.

6.2 New Operation Scenario Development

The Crawfordsville and Greenfield districts are located at the same approximate latitude and have similar climates. Therefore, the effect of weather is assumed to be identical in both districts when developing simulation scenarios. The similarity in location benefits the two districts, giving them the ability to share and integrate current district boundaries without significant seasonal climate and weather effects. District boundaries refer to the existing administrative boundaries of the two districts. Operational boundaries identified in the previous section are not the same as the district boundaries in this study. Four recommended simulation scenarios are proposed to maximize productivity and utilization while satisfying the current striping work load. Developing simulation scenarios is the first step to improving overall productivity and utilization improvement of each striping and district.

A primary goal of the proposed scenarios is to increase utilization of fleet operation in terms of number of striping trucks so that the optimum number of trucks can be operated in the two districts. The following factors were not considered in the four scenarios because they are randomly occurring and prove difficult to predict from the 2012 telematics data. The factors include:

- Weather patterns,
- Roadway construction, and O&M schedule factors,
- Human factors such as truck drivers habits,
- Striping truck specifications such as bead flow and paint tank capacities,
- Roadway design factors such as type of alignment, multilane or double lane, and divided highway.

All four simulation scenarios were based on 2012 seasonal striping truck operation data as shown in Table 6.9. Table 6.9 shows a summary of striping truck operation data acquired from telematics and INDOT's Work Management System (WMS). The data include actual operation days, total striping distances and average striping distances. The two data sets show different distances because telematics distance only measures the actual truck driving distance, regardless of striping type. Therefore, dual line striping, which is double the driving distance, is not taken into consideration for the striping distance measurement. On the contrary, WMS striping distance is actual striping distance regardless of truck driving distance. Striping crews manually input WMS distances after actual striping distance is accumulated by the paint gun gauges in the trucks. Striping distance data compared in Table 6.9 presents two distinctive differences between the two data collection methods. First, edge-line striping distance shows an approximate difference of one mile per day. Second, WMS centerline striping distance is approximately 50 percent longer than the distance taken from telematics striping data. From the current WMS data, it is almost impossible to identify whether a centerline truck stripes a solid line, skipped line, or a combination of the two. Telematics striping data reflects the overall performance regardless of which striping pattern was used. Therefore, telematics data will be used as a baseline for striping operation data when developing the following four scenarios.

Striping operation performance of each scenario is measured by a combination of a number of operation days and average striping distance obtained from 2012 telematics data. Maximum operation days based on simulated schedule and total striping distance is obtained by multiplying the operation days in a

TABLE 6.9
Summary of 2012 Striping Trucks Operation Days & Mileages

		Telematics Striping Data		WMS Striping Data	
Truck ID, District & Type	Actual Operation Days (2012)	Total Striping Distance	Average Striping Distance	Total Striping Distance	Average Striping Distance
61249 CF_EL	46 days	1,357 miles	30 miles/day	1,428 miles	31 miles/day
61457 CF_CL	66 days	1,211 miles	18 miles/day	1,910 miles	29 miles/day
63759 GR_EL	44 days	1,349 miles	31 miles/day	1,412 miles	32 miles/day
63597 GR_CL	80 days	1,368 miles	17 miles/day	2,021 miles	25 miles/day
Total	**236 days**	**5,285 miles**	**22 miles/day**	**6,771 miles**	**29 miles/day**

scenario and average striping distance. The telematics data in Table 6.9 is used as a baseline for all proposed scenarios striping distance calculations in following sections.

6.2.1 Simulation Scenarios 1 and 2

Scenarios 1 and 2 enhance the level of utilization and estimated striping distance by merging two district boundaries. Integrated scheduling between two districts was critical for scenarios 1 and 2 because districts have to share a centerline and an edgeline truck across the district boundaries.

The operation (working) days from April 1, 2012 to November 30, 2012 in each district are indicated by different colors in Figures 6.2 and 6.3. Overlapping days indicate that at least two trucks concurrently performed striping activity on the same day, but independently worked in each district. Overlapping days are indicated in gray. Most overlapping working days were during typical INDOT striping operation week days between Monday and Thursday. There were a significant number of non-working days, almost all on weekends. Non-working calendar days in Tables 6.11 and 6.12 were identified from telematics data and were shown in Figures 6.2 and 6.3 as white. Tables 6.11 and 6.12 include a summary of 2012 data along with two scenarios for two centerline and two edgeline trucks.

Two scenarios are based on the assumption that two districts can share a centerline and an edgeline striping truck. The benefit of these scenarios is from cutting the fleet size in half by eliminating two trucks, a centerline truck from one district and an edgeline truck from the other. Summaries of scenario 1 and 2 are as follows:

Simulation Scenario 1
Description:

- A centerline and an edgeline truck cover both districts.
- Each district operates either a centerline or an edgeline truck in two week intervals, and then trucks will be switched.
- Districts shall coordinate delivery of truck prior to Monday morning.
- Only typical week days from Monday to Friday are available for working days.
- Each district shall schedule all necessary activities including O&M during assigned week.
- Simulation scenario 1 uses a 2012 calendar for comparative study only as shown in Figures 6.2 and 6.3. Striping activity begins on April 1, 2012 and ends November 30, 2012.

Pros:

- It may provide maximum cost savings by eliminating 2 striping trucks (one edgeline and one centerline truck).
- It may improve productivity, average striping distance per operation day, because additional crews and vehicles can support and focus on a single trucks operation.
- It may maximize utilization rates of striping trucks.
- Districts may utilize weekend for maintenance and truck exchange, thus not impacting weekday schedule.

Cons:

- Crews and striping trucks need to continuously work all weekdays (Monday to Friday) during a striping season. Work schedule provides small allowance for maintenance on weekdays.
- Tight schedule may overburden crew work schedules.
- A specific type of striping operation (solid, skipped, or combination) may be limited due to limited availability of specific type of truck.
- Any major downtime, such as equipment breakage or unexpected weather, may significantly delay the overall striping schedule.

Simulation Scenario 2
Description:

Scenarios 1 and 2 are almost identical except for scheduling patterns. Scenario 2 schedule includes weekends and switches on a week day.

- A centerline and an edgeline truck cover both districts.
- Each district operates either a centerline or an edgeline truck in intervals of six working days, with a day buffer in between periods (see Figures 6.2 and 6.3).
- Each district sets its own operation plan and schedule during its possession of the truck.
- Weekends in scenario 2 are considered normal working days in terms of striping truck availability. Each district will determine its own detailed schedule during this time period.
- Simulation scenario 2 uses all days of the week, including weekends for comparative study only as shown in Figures 6.2 and 6.3. Striping activity begins on April 1, 2012 and ends November 30, 2012.

Pros:

- It may provide maximum cost savings by eliminating two striping trucks (one edgeline and one centerline truck).
- It may improve productivity, average striping distance per operation day, because additional crews and vehicles can support and focus on a single trucks operation.
- It may maximize utilization of striping trucks.
- Districts may have a more flexible work schedule than in scenario 1. In scenario 2, every Wednesday, at the end of the day, is set aside for exchanging trucks.

Cons:

- It may cause substantial impacts to crew work schedules during weekends.
- Tight schedule may overburden work crews.
- A specific type of striping operation (solid, skipped, or combination) may be limited due to availability of specific type of truck.
- Any major downtime due to equipment breakage or unexpected weather may significantly delay overall striping schedule.

Tables 6.10 and 6.11 provide a summary of operation and non-working days from scenarios 1 and 2. The tables indicate that the estimated operation days from the first two scenarios significantly exceed actual operation days obtained from 2012 telematics data.

6.2.2 Simulation Scenarios 1 & 2 Analysis

2012 average striping distance is taken as a datum (baseline) to estimate maximum striping distance for scenarios 1 and 2. Tables 6.12 and 6.13 summarize the estimated maximum operation days and striping distances for scenarios 1 and 2. The percentage comparisons in Tables 6.13 and 6.14 indicate additional maximum striping capacity when scenario 1 is adopted. Two striping trucks can be successfully utilized to perform the workload of four trucks. However, factors not considered in the scenarios may significantly affect the striping operation.

Assuming that the 2012 striping operation was a typical striping work load for any given year, edgeline truck utilization was significantly low in both districts. Thus, comparing edgeline utilization between 2012 striping data and simulated scenarios 1 and 2 shows a significant gap. Scenarios 1 and 2 show a range of approximately 80–140 percent additional capacity for edgeline striping but only marginal additional capacity for the centerline trucks.

6.2.3 Simulation Scenario 3

Scenario 3 is an alternative option to maximize the level of utilization of centerline trucks. Assuming that a centerline truck has functionality for performing both edgeline and centerline striping work, an edgeline truck is not necessary.

Simulation scenario 3 is operating only one centerline truck in each district. The scenario assumes that a crew works all five weekdays (Monday–Friday) per week during the striping season. Assuming that the 2012 striping season began on April 1, 2012 and ended on November 30, 2012, there are a total of 35 weeks during a typical striping season in this study. In addition, each district will have an autonomous work schedule that does not affect other districts. A centerline truck at each district can be operated five days per week for a maximum of 175 (5×35) working days as shown in Tables 6.14 and 6.15.

Simulation Scenario 3

Description:

- Each district operates only one centerline truck.
- Each district schedules its own operation plan.
- Only typical week days from Monday to Friday are available for working days.

Pros:

- It may provide significant cost savings by eliminating an edgeline truck from each district.
- It may improve productivity because additional crews and vehicles can support and focus on a single trucks operation.
- It may maximize utilization of centerline trucks.
- Districts may maintain their own autonomous work schedule and operation plan that provides a more flexible work schedule than scenarios 1 and 2.

Cons:

- There is no backup striping truck in scenario 3.
- Any major breakdown (mechanical problem) of any one of the striping trucks may seriously delay overall striping schedule.
- Districts may excessively use the centerline truck to keep up with the workload. A centerline truck is more costly to replace than an edgeline truck.
- A centerline truck may need to flush spray guns and paint reserve tanks more frequently due to color changes and restricted use of spray guns.

Since the two districts do not integrate their work schedules and trucks, scenario 3 summaries were made for each district. Tables 6.14 and 6.15 present a summary of scenario 3 for each district. Maximum operation days are based on the most feasible operation days in a striping season. Maximum striping distance (sixth column in Tables 6.14 and 6.15) is a result of multiplying average telematics striping distance data in 2012 from the fourth column and the number of operation day in 2012 in Tables 6.14 and 6.15. Regardless of the type of striping, a centerline striping trucks average daily striping distance was determined using two conditions:

- Crawfordsville centerline truck (61249) uses a centerline productivity rate of 18 miles/day, acquired from 2012 data to estimate maximum operation days in scenario 3. → Results: 56 percent (operation days) and 25 percent (striping distance) in Table 6.14.
- Greenfield centerline truck (63597) uses a centerline productivity rate of 17 miles/day, acquired from 2012 data to estimate maximum operation days in scenario 3. → Results: 41 percent (operation days) and 10 percent (striping distance) in Table 6.15.

Scenario 3 does not show a significant striping distance capability when just the average centerline productivity rate is used for both centerline and edgeline striping. It provides a maximum of only 10 and 25 percent (Tables 6.14 and 6.15, respectively) additional striping distance. Scenario 3 does not consider any factors that could potentially impair centerline truck productivity and utilization.

6.2.4 Simulation Scenario 4

Scenario 4 was created as a reinforcement option for scenario 3 to minimize the risk of utilizing a centerline truck. Simulation scenario 4 is based on the idea of operating one centerline truck in each district and an edgeline truck as a backup for both districts for only painting white lines. Any one of the two districts that needs to complete a significant amount of white striping will use the edgeline striping truck. This scenario assumes that crews work five weekdays (Monday–Friday) each week during the striping season. There are a total of 35 weeks during a typical striping season, from April 1 to November 30. A centerline truck in each district operates five days per week and a maximum of 175 (5×35) working days, as defined

Figure 6.2 Centerliner calendar for scenarios 1 and 2.

Figure 6.2 Continued.

Figure 6.3 Edgeliner calendar for scenarios 1 and 2.

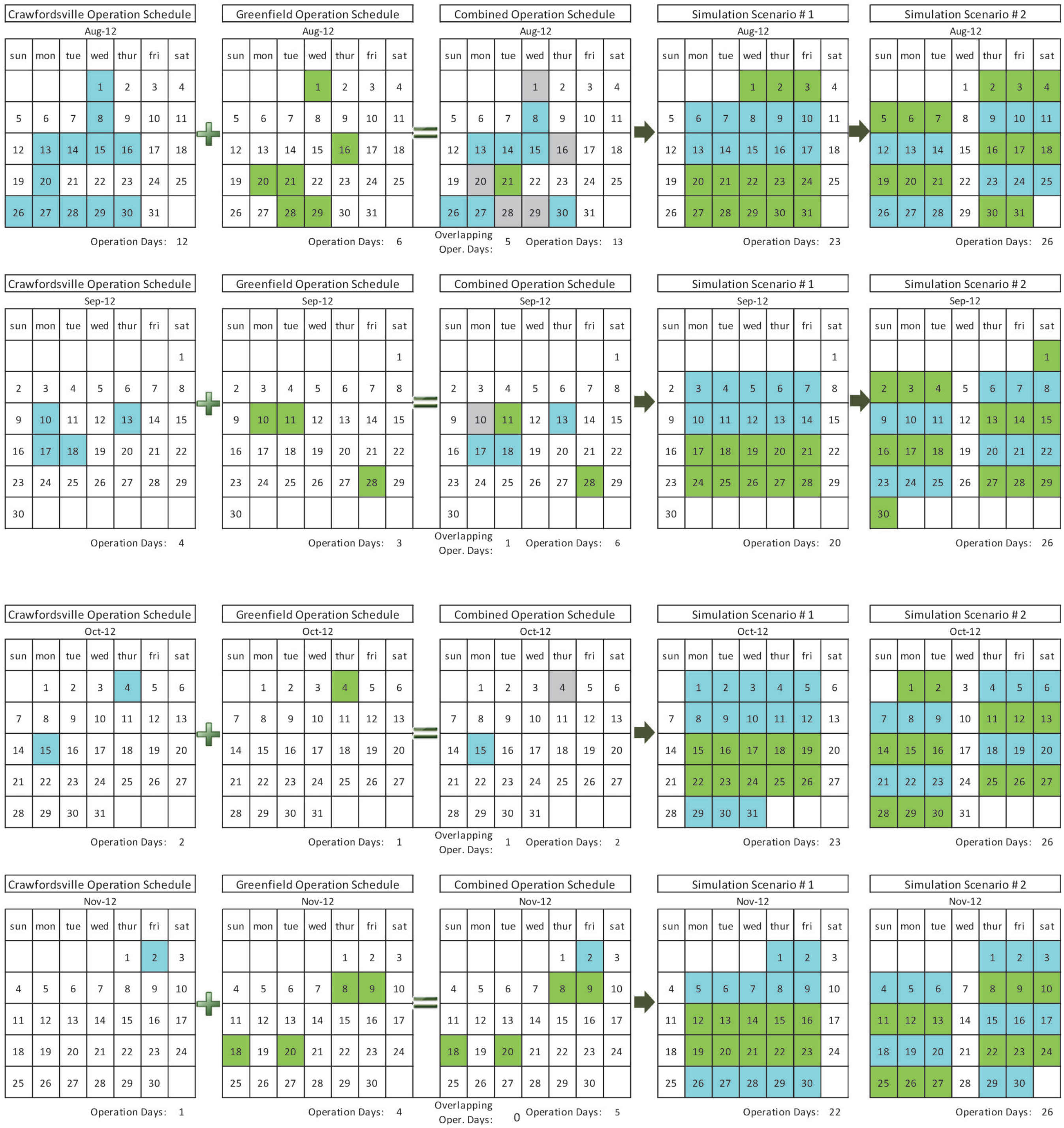

Figure 6.3 Continued.

TABLE 6.10
Summary of centerliner operation and scenarios 1 and 2

	Actual Operation in 2012 Striping Season				Scenario # 1			Scenario # 2		
Month	**Crawfordville Operation Days (61457)**	**Greenfield Operation Days (63597)**	**Overlaping Operation Days**	**Non-Working Calender Days in Both Districts**	**Crawfordsville Operation Days**	**Greenfield Operation Days**	**Non-Working Days**	**Crawfordsville Operation Days**	**Greenfield Operation Days**	**Non-Working Days**
April	5 days	0 days	0 days	25 days	11 days	10 days	9 days	14 days	12 days	4 days
May	11 days	13 days	8 days	15 days	13 days	10 days	8 days	13 days	13 days	5 days
Jun	12 days	16 days	11 days	13 days	11 days	10 days	9 days	12 days	14 days	4 days
July	11 days	14 days	8 days	14 days	12 days	10 days	9 days	12 days	15 days	4 days
Aug.	10 days	15 days	4 days	10 days	13 days	10 days	8 days	14 days	12 days	5 days
Sept.	8 days	12 days	7 days	17 days	10 days	10 days	10 days	14 days	12 days	4 days
Oct.	9 days	8 days	4 days	18 days	10 days	13 days	8 days	14 days	12 days	5 days
Nov.	0 days	2 days	0 days	28 days	10 days	12 days	8 days	12 days	14 days	4 days
Total	**66 days**	**80 days**	**42 days**	**140 days**	**90 days**	**85 days**	**69 days**	**105 days**	**104 days**	**35 days**

TABLE 6.11
Summary of Edgeliner Operation and Scenarios 1 and 2

	Actual Operation in 2012 Striping Season				Scenario # 1			Scenario # 2		
Month	**Crawfordville Operation Days (61249)**	**Greenfield Operation Days (63759)**	**Overlaping Operation Days**	**Non-Working Calender Days in Both Districts**	**Crawfordsville Operation Days**	**Greenfield Operation Days**	**Non-Working Days**	**Crawfordsville Operation Days**	**Greenfield Operation Days**	**Non-Working Days**
April	3 days	0 days	0 days	27 days	10 days	11 days	9 days	12 days	14 days	4 days
May	7 days	10 days	6 days	20 days	10 days	13 days	8 days	13 days	13 days	5 days
Jun	9 days	5 days	2 days	18 days	10 days	11 days	9 days	14 days	12 days	4 days
July	8 days	15 days	5 days	13 days	10 days	12 days	9 days	15 days	12 days	4 days
Aug.	12 days	6 days	5 days	18 days	10 days	13 days	8 days	12 days	14 days	5 days
Sept.	4 days	3 days	1 days	24 days	10 days	10 days	10 days	12 days	14 days	4 days
Oct.	2 days	1 days	1 days	29 days	13 days	10 days	8 days	12 days	14 days	5 days
Nov.	1 days	4 days	0 days	25 days	12 days	10 days	8 days	14 days	12 days	4 days
Total	**46 days**	**44 days**	**20 days**	**174 days**	**85 days**	**90 days**	**69 days**	**104 days**	**105 days**	**35 days**

TABLE 6.12
Scenario 1: Estimated Maximum Operation Days & Striping Mileages

Truck ID, District & Type	Telematics Striping Data (2012)			Scenario 1 Striping Data		Comparison (%)	
	Operation Days (AD)	Total Striping Distance (AS)	Average Striping Distance	Scenario 1 Maximum Operation Days (ED)	Scenario 1 Maximum Striping Distance (ES)	Operation Days $\frac{ED-AD}{AD}$	Striping Distance $\frac{ES-AS}{AS}$
61249 CF_EL	46 days	1,357 miles	30 miles/day	85 days	2,508 miles	85%	85%
61457 CF_CL	66 days	1,211 miles	18 miles/day	90 days	1,651 miles	36%	36%
63759 GR_EL	44 days	1,349 miles	31 miles/day	90 days	2,759 miles	105%	105%
63597 GR_CL	80 days	1,368 miles	17 miles/day	85 days	1,454 miles	6%	6%
Total	**236 days**	**5,285 miles**	**22 miles/day**	**350 days**	**8,372 miles**	**48%**	**58%**

NOTE: (ED − AD)/AD shows that the percentage difference between actual operation days and estimated operation days. (ES − AS)/AS shows that the percentage difference between actual striping distance and estimated striping distance.

TABLE 6.13
Scenario 2: Estimated Maximum Operation Days & Striping Mileages

Truck ID, District & Type	Telematics Striping Data (2012)			Scenario 2 Striping Data		Percent of Comparison	
	Operation Days (AD)	Total Striping Distance (AS)	Average Striping Distance	Scenario 2 Maximum Operation Days (ED)	Scenario 2 Maximum Striping Distance (ES)	Operation Days $\frac{ED-AD}{AD}$	Striping Distance $\frac{ES-AS}{AS}$
61249 CF_EL	46 days	1,357 miles	30 miles/day	104 days	3,068 miles	126%	126%
61457 CF_CL	66 days	1,211 miles	18 miles/day	105 days	1,927 miles	59%	59%
63759 GR_EL	44 days	1,349 miles	31 miles/day	105 days	3,219 miles	139%	139%
63597 GR_CL	80 days	1,368 miles	17 miles/day	104 days	1,778 miles	30%	30%
Total	**236 days**	**5,285 miles**	**22 miles/day**	**418 days**	**9,992 miles**	**77%**	**89%**

NOTE: (ED − AD)/AD shows that the percentage difference between actual operation days and estimated operation days. (ES − AS)/AS shows that the percentage difference between actual striping distance and estimated striping distance.

TABLE 6.14
Scenario 3: Crawfordsville Maximum Operation Days & Striping Mileages

Truck ID, District & Type	Telematics Striping Data (2012)			Scenario 3 Striping Data		Percent of Comparison	
	Operation Days (AD)	Total Striping Distance (AS)	Average Striping Distance	Scenario 3 Maximum Operation Days (ED)	Scenario 3 Maximum Striping Distance (ES)	Operation Days $\frac{(ED-\sum AD)}{\sum AD}$	Striping Distance $\frac{(ES-\sum AS)}{\sum AS}$
61249 CF_EL	46 days	1,357 miles	30 miles/day	N/A	N/A	N/A	N/A
61457 CF_CL	66 days	1,211 miles	18 miles/day	175 days	3,211 miles	56%	25%
Total	**112 days**	**2,568 miles**	**23 miles/day**	**175 days**	**N/A**	**N/A**	**N/A**

NOTE: (ED − ΣAD)/ΣAD shows the percentage difference between actual operation days and estimated operation days. (ES − ΣAS)/ΣAS shows the percentage difference between actual striping distance and estimated striping distance. N/A means that there is no data

TABLE 6.15
Scenario 3: Greenfield Maximum Operation Days & Striping Mileages

Truck ID, District & Type	Telematics Striping Data (2012)			Scenario 3 Striping Data		Percent of Comparison	
	Operation Days (AD)	Striping Distance (AS)	Average Striping Distance	Scenario 3 Maximum Operation Days (ED)	Scenario 3 Maximum Striping Distance (ES)	Operation Days $\frac{(ED-\sum AD)}{\sum AD}$	Striping Distance $\frac{(ES-\sum AS)}{\sum AS}$
63759 GR_EL	44 days	1,349 miles	31 miles/day	N/A	N/A	N/A	N/A
63597 GR_CL	80 days	1,368 miles	17 miles/day	175 days	2,993 miles	41%	10%
Total	**124 days**	**2,717 miles**	**22 miles/day**	**175 days**	**N/A**	**N/A**	**N/A**

NOTE: (ED − ΣAD)/ΣAD shows the percentage difference between actual operation days and estimated operation days. (ES − ΣAS)/ΣAS shows the percentage difference between actual striping distance and estimated striping distance. N/A means that there is no data.

in scenario 3. The edgeline truck is tentatively determined to be used approximately 100 days total in both districts for this study (50 days for each district).

Simulation Scenario 4

Description:

- A district primarily operates one centerline truck, with a standby edgeline truck for backup support.
- Each district schedules its own operation plan for its centerline truck, but needs to integrate a combined striping schedule for the edgeline truck.
- Only typical weekdays from Monday to Friday are available for working days.

Pros:

- A back-up edgeline truck in scenario 4 may help relieve tight work schedules that may exist in scenario 3.
- It may provide sufficient working resources for both districts.
- Districts may maintain their own autonomous work schedule and operation plan that provides more flexibility than scenarios 1, 2, and 3.

Cons:

- This scenario provides the least cost savings among the four scenarios by eliminating an edgeline truck from the two districts.
- Cost savings from minimizing fleet size is not significant when compared to other scenarios.
- A centerline truck may need to flush spray guns and paint reserve tanks more frequently because of color changes and temporarily halting operation.

Tables 6.16 and 6.17 indicate that an additional edgeline truck can significantly reduce work load in both districts. Assuming only 50 days of edgeline operations days per each district, an edgeline truck can most likely cover the edgeline work load of both districts combined.

6.2.5 Scenario Analysis

Table 6.18 provides a summary of various fleet sizes from the 2012 operation plan as well as the four scenarios. Scenarios 1 and 2 indicate maximum cost savings from reorganizing fleet sizes. Scenario 4 used one less edgeline truck than current fleet, but it is the most plausible scenario because it requires only minimal changes to the work schedule.

Table 6.19 provides a summary of the number of operation days from 2012 telematics data, and along with the operation days for each of the proposed scenarios. The results show that all four scenario operation plans can possibly replace the current operation plan. Scenario 4 indicates the highest possible number of maximum operation days of the four scenarios in Table 6.19.

Table 6.20 presents a summary of comparisons between actual striping distance in 2012 and maximum striping distances from the four scenarios. The striping distances were obtained by multiplying "Maximum Operation Days" in scenarios from Table 6.19 and "Average Striping Distance" from the 2012 telematics data. The scenario 2 indicates the largest potential of maximum striping distance.

According to the above analyses, no single scenario can maximize all three criteria: (1) minimum fleet size, (2) maximum working days, and (3) maximum striping distance. Decision makers shall consider many other factors and risks such as crew schedule, weather, construction schedule, truck maintenance and repair, supply chain of painting materials, and upgrade of striping truck work plans. Boundary integration between two districts might create other issues such as (1) how to create effective collaboration and work schedule integration between districts, and (2) how to minimize potentially excessive nonproductive driving distance between striping site and truck location. A pilot test may be required to verify and improve overall performance and cost savings.

6.3 Performance Metrics Development

The development of performance measurement metrics for striping truck operation provides an effective opportunity for INDOT to measure future performance. Performance metrics are developed under two categories: (1) productivity metrics and (2) utilization metrics. Productivity and utilization are two key performance indicators. Idling data is not sufficient for developing metrics because of two reasons. Firstly, idling is not

TABLE 6.16
Scenario 4: Crawfordsville District Estimated Maximum Operation Days & Striping Mileages

	Telematics Striping Data (2012)			Scenario 4 Striping Data		% Comparison	
				Scenario 4	Scenario 4	Operation Days	Striping Distance
Truck ID, District & Type	**Operation Days (AD)**	**Total Striping Distance (AS)**	**Average Striping Distance**	**Maximum Operation Days (ED)**	**Maximum Striping Distance (ES)**	$\frac{(ED-AD)}{AD}$	$\frac{(ES-AS)}{AS}$
61249 CF_EL	46 days	1,357 miles	30 miles/day	50 days	1,475 miles	9%	9%
61457 CF_CL	66 days	1,211 miles	18 miles/day	175 days	3,211 miles	165%	165%
Total	**112 days**	**2,568 miles**	**22 miles/day**	**225 days**	**4,686 miles**	**101%**	**82%**

NOTE: (ED − AD)/AD shows the percentage difference between actual operation days and estimated operation days. (ES − AS)/AS shows the percentage difference between actual striping distance and estimated striping distance.

TABLE 6.17
Scenario 4: Greenfield District Estimated Maximum Operation Days & Striping Mileages

	Telematics Striping Data (2012)			Scenario 4 Striping Data		% Comparison	
						Average Striping Distance	Striping Distance
Truck ID, District & Type	Operation Days (AD)	Total Striping Distance (AS)	Average Striping Distance	Operation Days (AD)	Total Striping Distance (AS)	$\frac{(ED-AD)}{AD}$	$\frac{(ES-AS)}{AS}$
63759 GR_EL	44 days	1,349 miles	31 miles/day	50 days	1,533 miles	14%	14%
63597 GR_CL	80 days	1,368 miles	17 miles/day	175 days	2,993 miles	119%	119%
Total	**124 days**	**2,717 miles**	**22 miles/day**	**225 days**	**4,525 miles**	**81%**	**67%**

NOTE: (ED − AD)/AD shows the percentage difference between actual operation days and estimated operation days. (ES − AS)/AS shows the percentage difference between actual striping distance and estimated striping distance.

TABLE 6.18
Fleet Size from Actual and Proposed Scenarios

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Truck Type	No. of current Fleet Trucks	No. of Suggested Fleet Trucks	No. of Suggested Fleet Trucks	No. of Suggested Fleet Trucks	No. of Suggested Fleet Trucks
Edgeline Truck	2	1	1	0	1
Centerline Truck	2	1	1	2	2
Total	**4**	**2**	**2**	**2**	**3**

TABLE 6.19
Maximum Operation Days from Proposed Scenarios

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
2012Actual Operation Days	Maximum Operation Days	(ED − AD) days	Maximum Operation Days	(ED − AD) days	Maximum Operation Days	(ED − AD) days	Maximum Operation Days	(ED − AD) days
236	350	114	418	182	350	114	450	214

NOTE: Estimated Maximum Operation Days (ED) − Actual Operation Days (AD) means that the difference between estimated and actual operation days.

TABLE 6.20
Maximum Striping Distances from Actual and Proposed Scenarios

		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Truck ID, District & Type	Telematics 2012Actual Striping Distance (Miles)	Striping Distance (Miles)	ES − AS (Miles)	Striping Distance (Miles)	ES − AS (Miles)	Striping Distance (Miles)	ES − AS (Miles)	Striping Distance (Miles)	ES − AS (Miles)
61249 CF_EL	1,357	2,508	1,151	3,068	1,711	N/A	N/A	1,475	118
61457 CF_CL	1,211	1,651	440	1,927	716	3,211	2,000	3,211	2,000
63759 GR_EL	1,349	2,759	1,410	3,219	1870	N/A	N/A	1,533	184
63597 GR_CL	1,368	1,454	86	1,778	410	2,993	1,625	2,993	1,625
Total	**5,285**	**8,372**	**3,087**	**9,992**	**4707**	**6,204**	**919**	**9,212**	**3,927**

NOTE: Estimated Maximum Striping Distance (ES) − Actual Striping Distance (AS) is the difference between estimated and actual striping distances. N/A means that there is no data.

directly related to striping performance in terms of striping distance. Secondly, the idling sensor was not configured at the beginning of the 2012 striping season to collect specific idling data in conjunction with striping operation. The current striping data used in productivity and utilization is based on an algorithm that calculates values from various types of driving distances and times. Therefore, idling metrics were excluded and two metrics, productivity and utilization, were developed to provide a performance measurement for future striping operations.

6.3.1 Productivity Metrics

A primary goal of productivity metrics is to conveniently determine a level of productivity without a comprehensive analysis of striping operation data. Current data is insufficient for developing statewide universal metrics because the data was only collected from two districts in a striping season. Thus, a suitable statistical data simulation method is required. Monte Carlo simulation was selected to develop productivity metrics. Monte Carlo simulation reduces potential statistical bias that might be caused from insufficient data.

Monte Carlo simulation is defined as a methodical use of sample means to estimate population means. It allows the creation of practical answers to complex questions by using appropriate actions with repetitive histories (*32*). According to previous studies, Monte Carlo simulation is a highly flexible and powerful form of numerical integration that can be applied to a wide range of fields such as nuclear physics, finance, and many other scientific practices (*32–34*).

The main objective of using Monte Carlo simulation is to simulate striping productivity based on 2012 striping operation data. The expected outcome of the Monte Carlo simulation is to provide simulated population data for developing productivity metrics. Microsoft Excel® is used to run Monte Carlo simulation.

6.3.1.1 Monte Carlo Simulation Development. An Edgeline striping truck in the Crawfordsville district (ID: 61249) was tested to validate the Monte Carlo simulation. The statistical mean value from 2012 striping data is 29.49 miles and the standard deviation is 14.54 miles. A higher standard deviation value corresponds to a wider spread of striping distance data points from the Crawfordsville edgeline truck in 2012. It means that daily striping mileages of Crawfordsville edgeline truck changed irregularly.

Monte Carlo simulation in this study uses a normal distribution as shown in Figure 6.4 (*35*). The normal distribution is based on statistical parameters from the 2012 striping operation data. Table 6.21 shows Monte Carlo simulation results using Microsoft Excel® function *"NORMINV(Random(), Mean, Stdev)"* for the Crawfordsville edgeline truck. The mean and standard deviation values in the simulation results will change because the random number updates every time the formula is run. The percentage of difference between the 2012 data and Monte Carlo data remains under 5 percent through numerous simulation trials. The percentage of

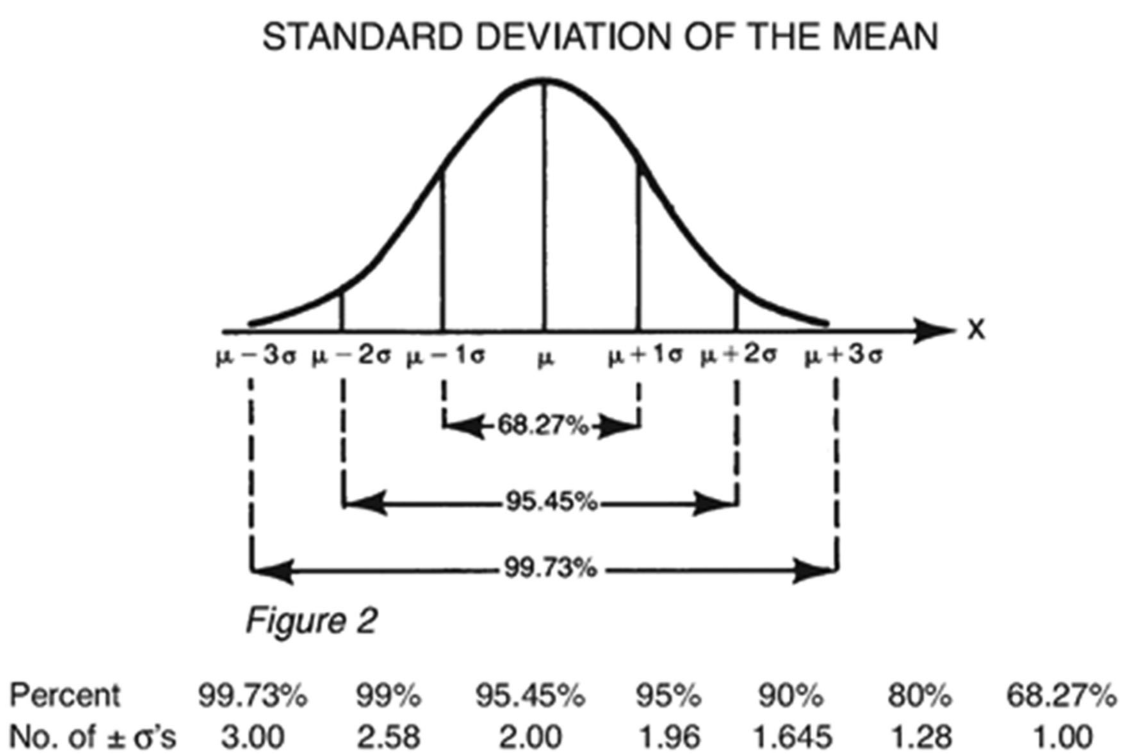

Figure 6.4 Normal distribution confidence intervals (*35*).

TABLE 6.21
Comparison of 2012 Striping Data and Monte Carlo Results: Crawfordsville Edgeline (61249)

Number of Monte Carlo Iteration	2012 Striping Data Mean (Miles)	Monte Carlo Mean (Miles)	Monte Carlo Standard Deviation	Percentage of Difference between 2012 Data andMonte Carlo Results
100	29.49	28.38	14.90	3.76%
1,000	29.49	29.20	14.67	0.97%
10,000	29.49	29.55	14.507	−0.20%
100,000	29.49	29.50	14.567	−0.02%

difference decreases as the number of Monte Carlo iterations increase. The percentage of difference in Table 6.21 is calculated by following Equation 6.1.

$$\textit{Percent of Difference} = \{(\textit{2012 Striping Data Mean} - \textit{Monte Carlo Mean})/\textit{2012 Striping Data Mean}\} \times 100 \qquad \text{(Eq. 6.1)}$$

The number of the Monte Carlo simulation iterations is determined by a confidence level of the normal distribution. The number of iterations is calculated by Equation 6.2 (*36*).

$$n = \left[\frac{100 \times Z_C S_X}{E\overline{x}}\right]^2 \qquad \text{(Eq. 6.2)}$$

Where,
n = *Number of iterations,*
Zc = *Number of sigma needed for specific confidence level,*
Sx = *Standard deviation of the sample,*
E = *Percentage error, and*
$\overline{x}$ = *Mean of the sample.*

Table 6.22 is a summary of data from calculating a number of iterations for each striping trucks based on 5 percent error. Average striping mileage per day and standard deviation are acquired from 2012 striping data collection. A normal distribution is assumed for all four trucks. The number of iterations shown is the minimum number of iterations for the Monte Carlo simulation to satisfy percentage error requirement (5 percent) for a 95 percent confidence level. Table 6.23 shows a summary of Monte Carlo simulation results from all four striping trucks. The percentage of mean difference between 2012 striping data and Monte Carlo simulated data is not a fixed value. Due to the nature of using random number generation in the Monte Carlo simulation method, the values from Monte Carlo simulation are different for every run of the simulation.

6.3.1.2 Productivity Metrics Definition & Measurement Ranges. Productivity metrics are proposed as shown in Table 6.24. Simplicity is a key aspect of metrics development for convenience of implementation. Three levels of productivity measurement are proposed as defined in Table 6.24. There are two sets of Monte Carlo results. One is edgeline truck metrics and the other is centerline metrics. Figure 6.5 shows a diagram for probability density functions based on a normal distribution. Probability ranges for each metric are shown in the distribution diagram.

Tables 6.25 and 6.26 are summaries of the statistical analysis of 2012 striping data for the edgeline and centerline trucks. As shown in Tables 6.27 and 6.28, 2012 striping data can be classified based on the productivity metrics to instantly identify the level of productivity on a daily basis.

6.3.1.3 Productivity Metrics Application. For future application, two sets of productivity metrics are developed using Monte Carlo simulations as shown in Tables 6.29 and 6.30. Metrics in Table 6.29 would be used for edgeline trucks and metrics in Table 6.30 would be used for centerline trucks. However, range values (mpd: miles per day) from the Monte Carlo simulation are subject to change under two conditions:

- Striping data shall be updated by adding more seasonal data. Current values in the metrics are based solely on 2012 striping data.
- Proposed metric values are from Monte Carlo simulation. The values are subject to change, but the magnitude of those changes is typically insignificant.

TABLE 6.22
Number of Iterations for 95 Percent Confidence Level

Variables	61249 Crawfordsville Edgeline Truck	61457 Crawfordsville Centerline Truck	63759 Greenfield Edgeline Truck	63597 Greenfield Centerline Truck
n	374	559	428	698
z_c	1.96	1.96	1.96	1.96
S_x	14.54	11.07	16.18	11.67
E (%)	5.00	5.00	5.00	5.00
$\overline{x}$	29.49	18.34	30.65	17.32

TABLE 6.23
Percentage Error between Estimated and True mean of the Striping Mileages—All Striping Trucks

ID, District, Truck Type	2012 Striping Data Mean (Miles)	Number of Monte Carlo Iteration	Monte Carlo Mean (Miles)	Monte Carlo Standard Deviation	Percent of Difference between 2012 Data and Monte Carlo Results
61249 Crawfordsville Edgeline Truck	29.49	374	28.85	14.64	2.16%
61457 Crawfordsville Centerline Truck	18.34	559	18.42	11.40	−0.42%
63759 Greenfield Edgeline Truck	30.65	428	30.38	15.50	0.89%
63597 Greenfield Centerline Truck	17.32	698	17.15	11.71	0.97%

TABLE 6.24
Normal Distribution Probability Percentages Metrics

Metrics	Metrics Definition
Low Productivity	Any measured striping mile per day is less than or equal to 30% as compared to Monte Carlo result (miles/day ≤ 30%).
Medium Productivity	Any measured striping mile per day is more than 30% and less than or equal to 70% (30% < miles/day ≤ 70%).
High Productivity	Any measured striping mile per day is more than 70% as compared to Monte Carlo result (miles/day > 70%).

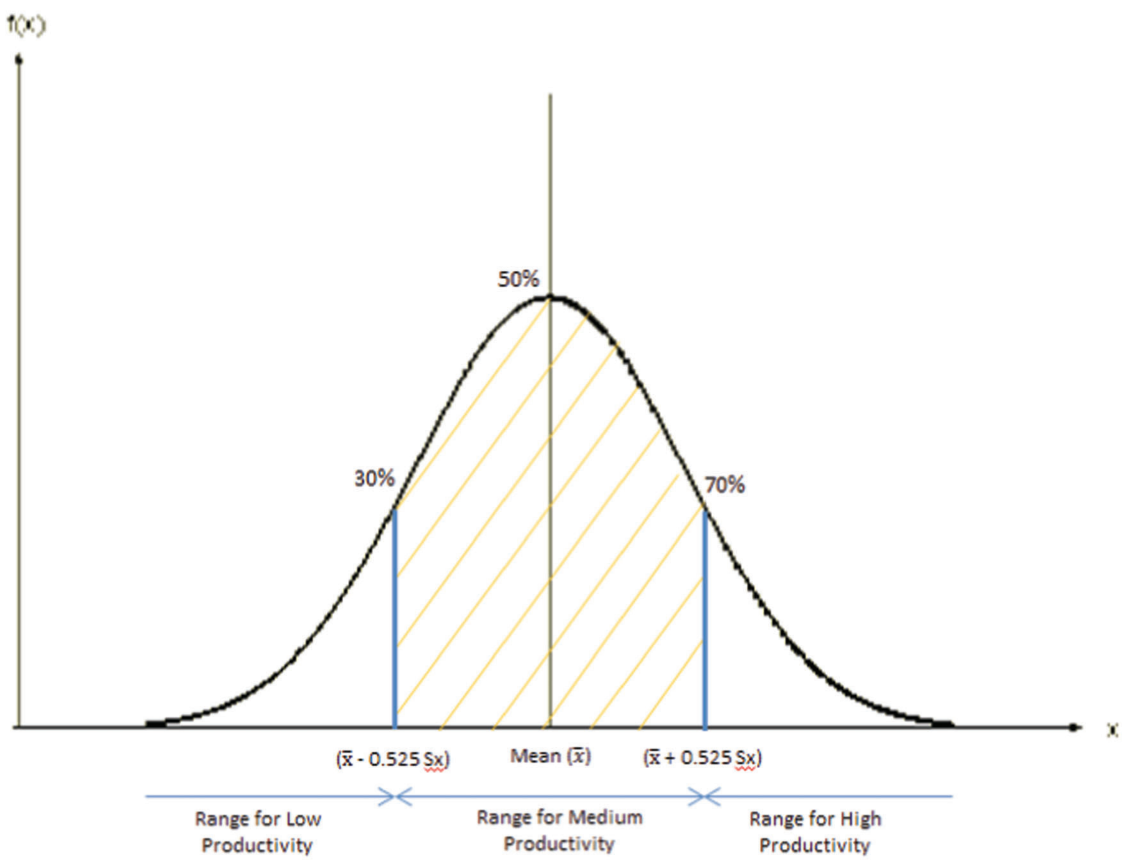

Figure 6.5 Probability density ranges from a normal distribution.

TABLE 6.25
2012 Edgeline Truck Data Analysis

Statistics	Crawfordsville (Miles/Day)	Greenfield (Miles/Day)	Averaged (Miles/Day)
Max	53.86	59.32	59.32
Min	0.68	0.48	0.48
Mean	29.49	30.65	30.06
Standard Deviation	14.54	16.18	15.29

TABLE 6.26
2012 Centerline Truck Data Analysis

Statistics	Crawfordsville (Miles/Day)	Greenfield (Miles/Day)	Averaged (Miles/Day)
Max	45.13	52.43	52.43
Min	0.35	0.06	0.06
Mean	18.34	17.32	17.78
Standard Deviation	11.07	11.67	11.37

TABLE 6.27
2012 Edgeline Truck Data Application to Productivity Metrics

Metrics	Crawfordsville (Days)	Greenfield (Days)	Combined Districts (Days)
Low (miles/day ≤ 30%)	14	14	28
Medium (30% < miles/day ≤ 70%)	16	14	30
High (miles/day > 70%)	16	16	32
Total	**46**	**44**	**90**

TABLE 6.28
2012 Centerline Truck Data Application to Productivity Metrics

Metrics	Crawfordsville (Days)	Greenfield (Days)	Combined Districts (Days)
Low (miles/day ≤ 30%)	22	27	48
Medium (30% < miles/day ≤ 70%)	26	33	64
High (miles/day > 70%)	18	19	33
Total	**66**	**79**	**145**

TABLE 6.29
Edgeline Striping Truck Performance Metrics

Metrics	Ranges	Monte Carlo Simulation (1)
Low	Miles/day ≤ 30 %	Striping Distance ≤ 21.676 mpd(2)
Medium	30 % < miles/day ≤ 70 %	21.676 mpd < Striping Distance ≤ 38.184 mpd
High	Miles/day > 70 %	Striping Distance > 38.184 mpd

(1): the values in the range (mpd) are subject to change. (2): mile/day

TABLE 6.30
Centerline Striping Truck Performance Metrics

Metrics	Ranges	Monte Carlo Simulated Data[1]
Low	Miles/day ≤ 30 %	Striping Distance ≤ 11.975 mpd[2]
Medium	30 % < miles/day ≤ 70 %	11.975 mpd < Striping Distance ≤ 23.888 mpd
High	Miles/day > 70 %	Striping Distance > 23.888 mpd

[1]The values in the range (mpd) are subject to change.
[2]Miles/day.

6.3.2 Utilization Metrics

Utilization is defined in this study as counting the number of monthly striping operation days in a striping season, regardless of striping distance. A primary goal of utilization metrics is to determine a level of utilization without comprehensive analysis of striping operation data. Utilization also represents effectiveness of striping operation scheduling and planning between districts.

Two statistical methods were considered to develop the utilization metrics: a box and whisker diagram and triangle distribution. A box and whisker diagram is a descriptive statistic method typically using a normal distribution and percentile of probability. A triangular distribution is selected for this study in lieu of a normal distribution because of limited 2012 striping utilization data.

6.3.2.1 Box and Whisker Diagram. According to Meyers, Gamst & Guarino (*37*), a box and whisker diagram is a histogram-like method of displaying data introduced by John Walter Tukey. Figure 6.6 shows an example of a box and whisker diagram using a normal distribution (*38*). This statistical graph is very efficient in comparing center and spread of two or more data sets. It is a useful method of graphically depicting groups of numerical data using five numerical values: (1) the smallest observation (sample minimum), (2) lower quartile (Q1), (3) median (Q2), (4) upper quartile (Q3), and (5) the largest observation (sample maximum).

Meyers, Gamst & Guarino (*37*) further explained box diagram quartiles. Quartiles separate the original data into four equal parts. Each of these quartiles contains one fourth of the data. The first quartile is the middle of the lower half of the data. The second quartile is the median of the entire set of data and third quartile is the middle of the upper half of the data. Sometimes the data set will have outliners. Outliners can be determined by finding the value of interquartile range (IQR) of the data. IQR is the distance between the third (Q3) and first (Q1) quartiles of the data. Every point above 1.5 IQR from Q3 and below 1.5 IQR from Q1 is defined as an outliner. Box plots can be drawn either horizontally or vertically.

A box and whisker diagram is a descriptive statistical method. As shown in Figure 6.6, ranges between quartiles can be used for developing performance metrics. However, as noted earlier, 2012 striping data only produces two data points for each month and each type of striping truck in each district. Thus, a box and whisker diagram with a normal distribution is not used in this research, but it can be used for developing utilization metrics in the future.

6.3.2.2 Triangular Distribution. Triangular distribution has been used in the project management field especially when sample size is very limited. Triangular distribution offers comprehensibility to the project planner (*39*). Triangular distribution may produce a subjective probability because of a decision known as modal value (c). Unlike a normal distribution having the same mean and median values, the modal value is the highest probability. A triangular distribution is not necessarily a symmetric shape. Referring to Figure 6.7, the modal value (c) is located between a (minimum) and b (maximum).

Forbes, Evans, Hastings & Peacock (*40*) suggested cumulative density function (CDF) Equations 6.3 and 6.4 as follows:

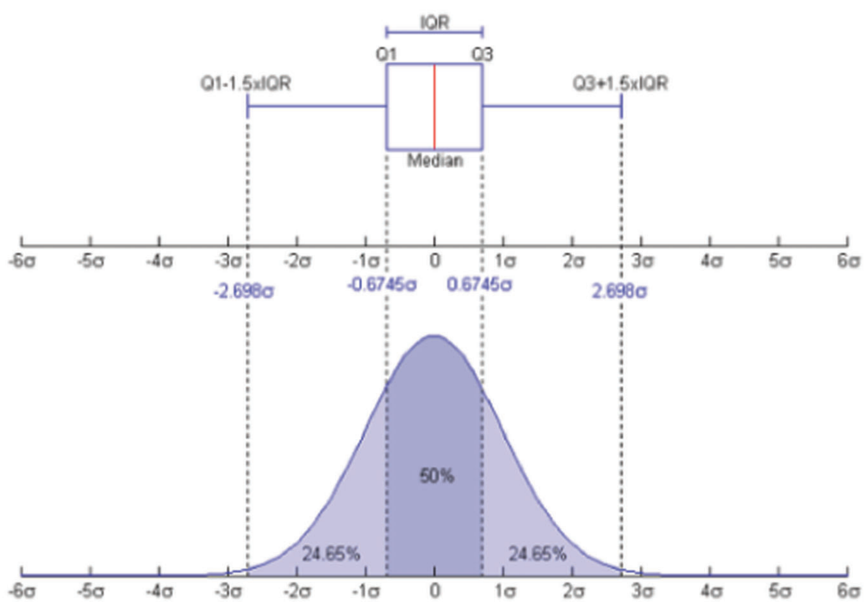

Figure 6.6 Box and whisker diagram (*38*).

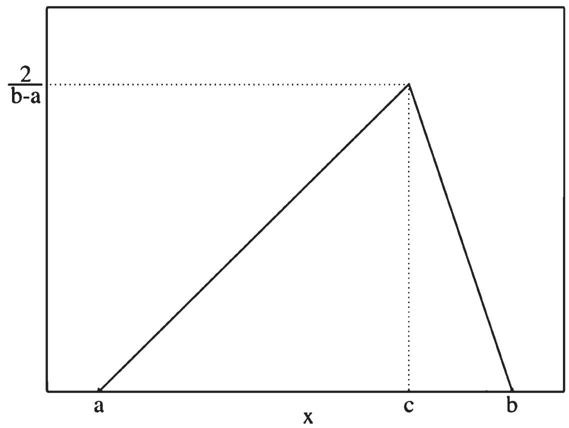

Figure 6.7 A Typical triangular distribution probability density function.

$$\frac{(x-a)}{(b-a)(c-a)} \ if \ a \leq x \leq c \qquad \text{(Eq. 6.3)}$$

$$1-\frac{(b-x)^2}{(b-a)(b-c)} \ if \ c \leq x \leq b \qquad \text{(Eq. 6.4)}$$

Where,
x = data point between a and b,
a = minimum data value,
b = maximum data value, and
c= modal value (mode).

6.3.2.3 Striping Data Triangular Distribution Analysis. 2012 striping data is analyzed to count the number of operation days from the 2012 daily striping summary report. The number of operation days from either Crawfordsville or Greenfield is used to determine minimum data value (a) and maximum data value (b). The range of the triangular distribution is the difference between (a) and (b). The triangular distribution for utilization metrics development is assumed to be symmetrical in this study. The modal value (c) is also the median value between (b-a) as shown in Tables 6.31 and 6.32.

Figures 6.8 and 6.9 summarize 2012 striping truck monthly operation days. The number of operation days for each truck changes based on operation month, truck type and district location.

6.3.2.4 Utilization Metrics Development and Measurement Ranges. Utilization metrics are developed based on triangular cumulative distribution function. Table 6.33 shows definitions of each metric ranging from low utilization to high utilization. To be consistent, the proposed ranges used for productivity metrics are also used in utilization metrics.

Triangular cumulative distribution uses following Equations 6.5–6.8:

$$x < a, 0 \qquad \text{(Eq. 6.5)}$$

$$a \leq x \leq c, \ x = a + \sqrt{(cdf) * (b-a) * (c-a)} \qquad \text{(Eq. 6.6)}$$

$$c < x \leq b, \ x = b - \sqrt{(1-cdf) * (b-a) * (b-c)} \qquad \text{(Eq. 6.7)}$$

$$b < x, 1 \qquad \text{(Eq. 6.8)}$$

Where,
x = data point in between a and b,
a = minimum data value,
b = maximum data value
c= modal value (mode), and
cdf = cumulative density function in decimal.

The metrics ranges during April 2012 for a centerline striping truck are calculated as an example. The first step of utilization metrics calculations is to determine *a, b, c and cdf percent*. As shown in Table 6.31, the maximum value is 5, the minimum value is 0 days, and the modal value is 2.5 days. Maximum value for the low utilization (x) is 30 percent cdf (0.3) of the cumulative distribution function and calculated by Equation 6.6.

The maxinum number of operation days in low utilization metrics is:

TABLE 6.31
2012 Striping Data for Centerline Truck Operation Days

2012 Months	61457 Crawfordsville Centerline Truck (Days)	63597 Greenfield Centerline Truck (Days)	b-a (Days)	c (Days)
April	5	0	5	2.5
May	11	13	2	12
Jun	12	16	4	14
July	11	14	3	12.5
August	10	15	5	12.5
September	8	12	4	10
October	9	8	1	8.5
November	0	2	2	1
Total	66	80	26	73

TABLE 6.32
2012 Striping Data for Edgeline Truck Operation Days

2012Months	61249 Crawfordsville Edgeline Truck (Days)	63759 Greenfield Edgeline Truck (Days)	b-a(Days)	c(Days)
April	3	0	3	1.5
May	7	10	3	8.5
Jun	9	5	4	7
July	8	15	7	11.5
August	12	6	6	9
September	4	3	1	3.5
October	2	1	1	1.5
November	1	4	3	2.5
Total	46	44	28	45

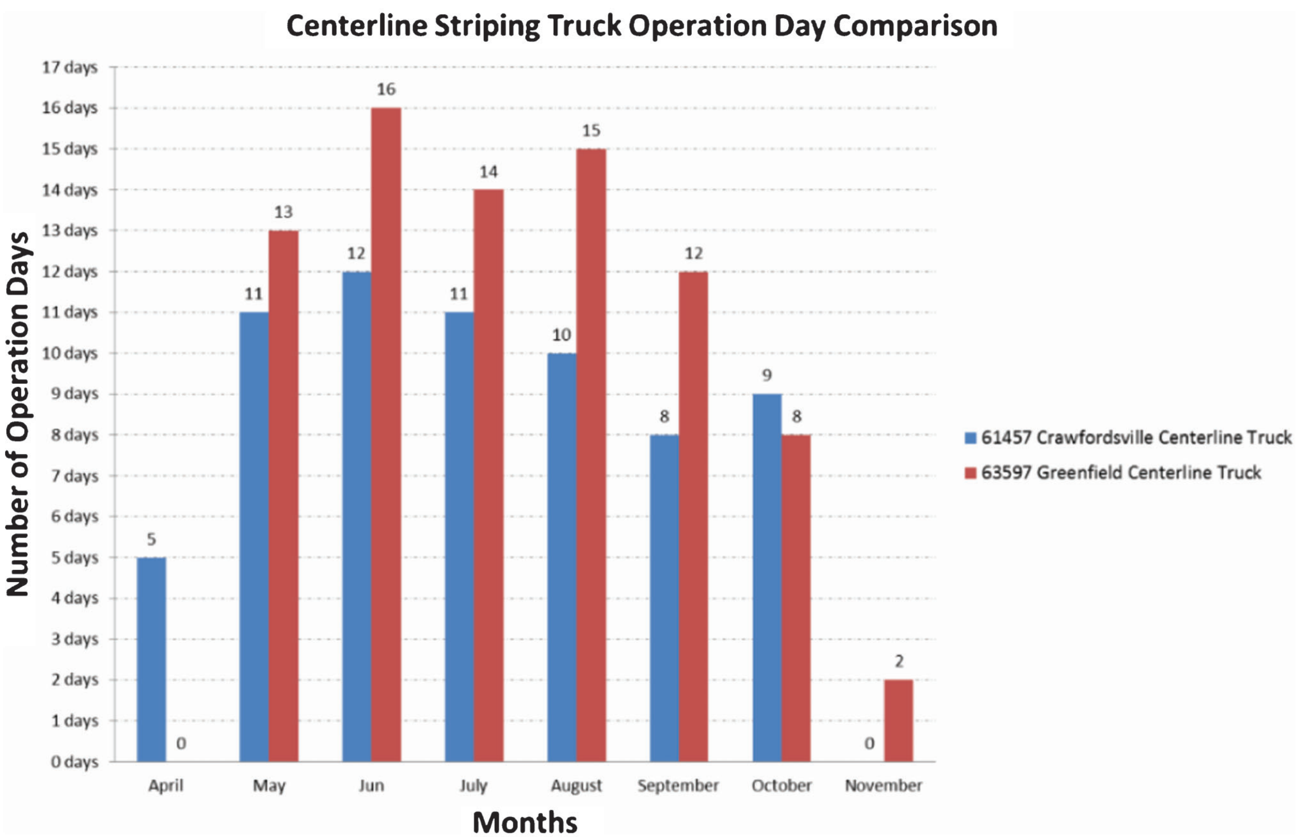

Figure 6.8 Centerline striping trucks monthly operation days.

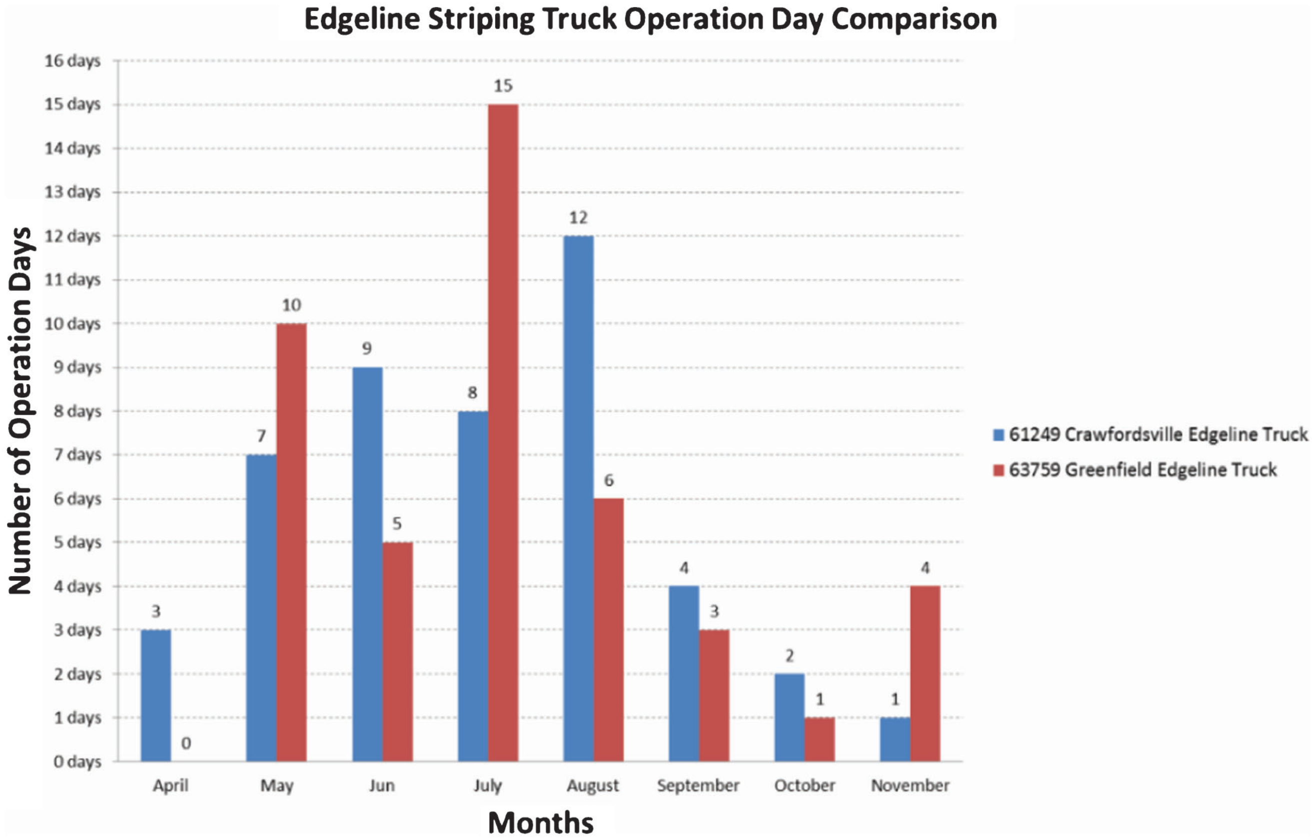

Figure 6.9 Edgeline striping trucks monthly operation days.

TABLE 6.33
Triangular Distribution Percentage Metrics

Metrics	Metrics Definition
Low Utilization	Any measured truck operation day per month is less than or equal to 30% as compared to triangular distribution result (days/month ≤ 30%).
Medium Utilization	Any measured truck operation day per month is more than 30 % and less than or equal to 70% (30% < days/month ≤ 70%).
High Utilization	Any measured truck operation day per month is more than 70 % as compared to triangular distribution result (days/month > 70 %)

$$x \leq (0 + \sqrt{0.30 * (5-0) * (2.5-0)} = 1.94 \text{ days}$$

For medium and high utilization metrics calculations, Equation 6.7 should be used because x is in between c and b.

The mininum number of operation days in high utilization metrics is:

$$x > (5 - \sqrt{(1-0.70) * (5-0) * (5-2.5)} = 3.06 \text{ days}$$

The metrics are calculated and summarized in Tables 6.34 and 6.35. Figures 6.10 and 6.11 present the utilization metrics in a graphical diagram for easy comparison with future striping season utilization data and a utilization performance trend in terms of the number of operation days.

TABLE 6.34
2012 Centerline Striping Truck Metrics Performances

2012Months	61457 Crawfordsville Centerline Truck(Days)	63597 Greenfield Centerline Truck(Days)	Low(days/month ≤ 30%)	Medium(30% < days/month ≤ 70%)	High(days/month > 70%)
April	5	0	≤ 1.94	1.94 < dpm[1] ≤ 3.06	> 3.06
May	11	13	≤ 11.77	11.77 < dpm ≤ 12.23	> 12.23
Jun	12	16	≤ 13.55	13.55 < dpm ≤ 14.45	> 14.45
July	11	14	≤ 12.16	12.16 < dpm ≤ 12.84	> 12.84
August	10	15	≤ 11.94	11.94 < dpm ≤ 13.06	> 13.06
September	8	12	≤ 9.55	9.55 < dpm ≤ 10.45	> 10.45
October	9	8	≤ 8.39	8.39 < dpm ≤ 8.61	> 8.61
November	0	2	≤ 0.77	0.77 < dpm ≤ 1.23	> 1.23

[1]dpm = operation days per month.

TABLE 6.35
2012 Edgeline Striping Truck Metrics Performances

2012Months	61249 Crawfordsville Edgeline Truck(Days)	63759 Greenfied Edgeline Truck(Days)	Low(days/month ≤ 30%)	Medium(30% < days/month ≤ 70%)	High(days/month > 70%)
April	3	0	≤ 1.16	1.16 < dpm[1] ≤ 1.84	1.84 >
May	7	10	≤ 8.16	8.16 < dpm ≤ 8.84	8.84 >
Jun	9	5	≤ 6.55	6.55 < dpm ≤ 7.45	7.45 >
July	8	15	≤ 10.71	10.71 < dpm ≤ 12.29	12.29 >
August	12	6	≤ 8.32	8.32 < dpm ≤ 9.68	9.68 >
September	4	3	≤ 3.39	3.39 < dpm ≤ 3.61	3.61 >
October	2	1	≤ 1.39	1.39 < dpm ≤ 1.61	1.61 >
November	1	4	≤ 2.16	2.16 < dpm ≤ 2.84	2.84 >

[1]dpm = operation days per month.

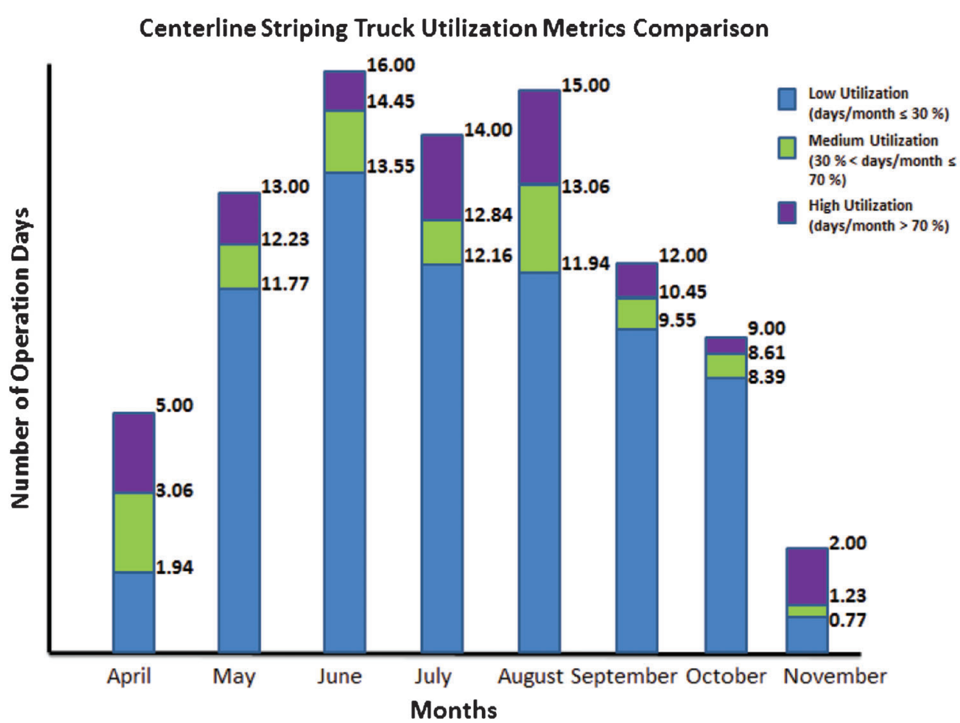

Figure 6.10 Centerline striping truck utilization metrics comparison.

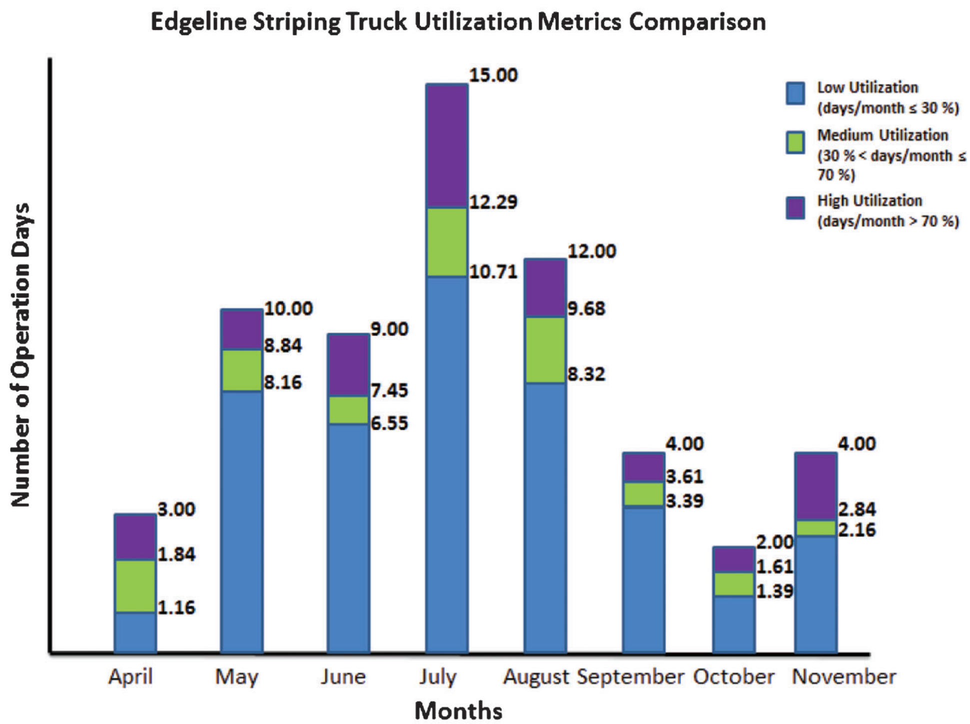

Figure 6.11 Edgeline striping truck utilization metrics comparison.

7. CONCLUSIONS

The research project began in January 2012 and was completed in June 2013. The main objective was to provide an accurate overview of current roadway striping operations and to validate a new data tracking application using telematics technology to be used in Crawfordsville and Greenfield districts. Roadway striping is one of INDOT's main maintenance operations and requires a significantly high level of resources and investment. The research results can be utilized to develop a new fleet operation and organization plan. The new fleet operation and organization plan aims to maximize performance of existing roadway striping operations and optimize of the size of the vehicle fleet in preparation of future fleet procurement.

Prior to telematics, the striping operation data was only reported through WMS, mainly for job costing purposes. Performance measurement, including real-time operational data collection and geographical tracking, is not provided by WMS. Gauge Telematics Inc. provides advanced data collection and process systems using telematics. Gauge Telematics configured and installed sensors so that collected data can be transmitted via a wireless network to a web database server in real-time, and becomes accessible everywhere through the internet. Initial data collection was conducted as a pilot test late in the striping season, in Fall 2011. This pilot data collection and initial analysis are described in Task 2.

Task 3 includes the collection of striping data from the entire 2012 striping season. The data were collected from April 2012 to November 2012. Gauge Telematics had continuously updated sensor configurations and website data processes. Task 3 provides a good overview of existing striping operation performance described using six sub-tasks found in chapter 5.0. The most significant finding is that the productivity, measured in actual striping distance compared to total driving distance, is only 15–25 percent. Utilization ratios indicate that centerline trucks were utilized at significantly higher rates than edgeline trucks, and the overall utilization ratio is between 20 and 30 percent. Idling analysis shows significantly different patterns among striping trucks and supporting vehicles. The average idling ratio varies between 6 and 38 percent for striping trucks. Total savings from eliminating unnecessary idling is estimated to be more than $ 200,000 U.S. dollars from both districts. Paint and bead volume analysis is based on data from WMS. Unit rates of material consumption per striping mile are summarized. A geospatial operation tracking function is provided via the website. Any user can track the location of a striping truck during a given period of time. Striping speed can be expressed using different segments on the website. However, the map function needs to be further improved to effectively show striping locations with specific speed ranges.

Task 4 includes three sub-tasks: (1) operational boundary analysis, (2) scenario recommendations, and (3) performance metrics. Existing operations indicate excessive nonproductive driving due to the fact that cumulative nonproductive distances, including start-to-site, transit between two sites, and finish-to-site, are too excessive. The proposed solution is to utilize a new deployment plan in which a truck completes striping workloads within one sub-district and then moves to the next sub-district boundary. This new deployment plan requires extensive pre-planning as well as mobile crews. The research examines four scenarios made to meet the objectives of new operation plans. All four scenarios were proposed to improve overall productivity and utilization by reducing the size of the existing fleet, modifying work schedule and crossing administrative district boundaries for truck deployment. The maximum savings and striping potential can be obtained from scenario 2. Performance metrics were divided into two categories: (1) productivity and (2) utilization. Productivity metrics use daily striping data, and the amount of data is sufficient enough to use Monte Carlo simulation and the concept of normal distribution. The productivity metrics were divided into three categories: (1) low productivity is when the calculated value is less than or equal to 30 percent of mean value from Monte Carlo simulation, (2) medium productivity occurs when it is more than 30 percent and less than or equal to 70 percent, and (3) high productivity occurs when it is over 70 percent. Striping miles for any given day will be compared to the metrics and a magnitude of productivity shall be determined. Utilization metrics use the concept of triangular distribution. Utilization was summarized in terms of the number of operation days in a month. The mode of all triangle distributions (c value) was assumed to be at the median between the minimum (a) and maximum (b) values. The utilization metrics were divided into three categories using the same structure as the productivity metrics. Performance metrics can be implemented to measure future striping operations, and be continuously improved if more data becomes available. The only available data used in this research was from April 01, 2012 to November 30, 2012 in the Crawfordsville and Greenfield districts.

Tasks 3 and 4 indicate that there is a significant chance to improve the existing roadway striping operation. Telematics has proved to be an effective and efficient data collection and processing technology when used to examine roadway striping operations. Application of the telematics technology can be expanded to other districts and maintenance operations to achieve the same objectives of this research. This final report summarizes all findings from the research. Several assumptions made about operation data analyses should be recognized by readers. INDOT should use their discretion when applying the proposed recommendations and metrics. Further discussion is open until October 2012.

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APPENDIX. USER MANUAL FOR SMART HUB WEBSITE

The *User Manual for Smart Hub Website* is available here: http://docs.lib.purdue.edu/cgi/viewcontent.cgi?filename=2&article=3042&context=jtrp&type=additional

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

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